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EVALUATION OF A HYDRO-PNEUMATIC FLOATING FENDER OR CAMEL

June 1963

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

EVALUATION OF A HYDRO-PNEUMATIC FLOATING FENDER OR CAMEL

Task No. Y-F015-10-303

Type C

by

T. T. Lee

ABSTRACT

This work is part of an effort to develop a family of camels (floating fenders) which will be lower in combined first cost and maintenance costs than existing fenders and will reduce damage to ship-hulls or to pier fender systems. The performance in Port Hueneme (California) Harbor of a pair of 50-foot-long hydro-pneumatic camels has been studied over a four-month period. This type of camel employs a floating bulkhead, fronted by two each 40" x 60" pneumatic- and hydro-rubber ship-fenders. The hydro-fenders exert their greatest resistance during high-rise-time impact loads while the pneumatic fenders are capable of absorbing more energy when the impact is of small magnitude and long duration. The rubber cushion units of each camel have a total minimum energy absorbing capacity of 20 foot-tons with a maximum ~~of~~ 86 ft-tons. The capacity depends on the initial air pressure (from 6 to 24 psig) in the pneumatic fenders and the impact characteristics of the ship for the hydro-fenders.

Since the launching of these camels on 8 March 1963, a total of fifteen ships (8000 to 20,000 tons) have been served. The camel is considered to have been satisfactory, except for the creation of **cargo-handling** problems (the camel holds ships too far off dock for service by on-board booms). The ship captains interviewed generally showed enthusiasm. Impact loading induced by the ships is relatively light and only 4.2 to 24.6 long-tons were measured. The kinetic energy absorbed was 1.5 to 17 ft-tons which is only 2% to 20% of the maximum designed capacity (or 8% to 84% of the minimum designed capacity). Ship velocity as measured varied from 0.1 to 0.75 foot per second. There were no marine-biological hazards on the camel after four months of immersion in the water. Evaluation will be continued in FY-64.

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INTRODUCTION

The Bureau of Yards and Docks (BUDOCKS) assigned the U. S. Naval Civil Engineering Laboratory (NCEL) the task of developing a family of camels to serve as floating separators between ships and fender systems of berthing structures. Replies by thirty-three Naval Shore Establishments to a NCEL questionnaire, on such subjects as traffic, berthing procedures, environment, use of camels, and damages are discussed by Green (1962)¹. Two camels of respectively the hydraulic and torsional type as proposed by NCEL are described by Leendertse (1962)². They provide an energy-absorbing capacity of 25 foot-tons each. However, BUDOCKS decided that they were too complicated and costly for normal use at Naval activities and subsequently designed one whose test operation is reported on herein. The BUDOCKS design employs a floating bulkhead, fronted by either four standard 40" x 60" pneumatic rubber ship-fenders or two each pneumatic and hydro rubber ship-fenders. The hydro fenders provide sufficient protection to the pier fenders during impact of the ship at a relatively high-rise-time but are deficient for low-rise-time impact loads. The pneumatic fenders have the opposite characteristics. Thus a combination of the two types provides protection to both pier and ship over the complete range of ship-impact loads.

DESCRIPTION OF CAMEL

The basic element in the BUDOCKS-designed NCEL-tested camel is a 50-foot long, 1'8" wide, 11'6" high floating bulkhead (Figure 1). The bulkhead is protected by two 40" x 60" pneumatic rubber ship-fenders with a minimum 6.6 psig or higher, up to 24 psig, initial air pressure, and two similar fenders filled with water. These rubber cushion units have a total minimum energy-absorbing capacity of 20 foot-tons and a maximum of 86 ft-tons. However, in practice, only a few rubber fenders make contact with the ship; therefore, even the minimum total energy-absorption capacity is not utilized. For recovery purposes, the water-filled fenders are packed with rubber hoses which serve to spring the fenders back to their undisturbed shape after the ship's load is removed. They are secured to the bulkhead with their axis horizontally instead of vertically as for the pneumatic fenders. An 18" pipe filled with sectional concrete cylinders is used as ballast weights.

The floating bulkhead is made of timber and steel materials with the core poured with polyurethane foam (see Appendix A) for increased buoyancy purposes. All timber members are treated with coal-tar creosote oil to increase resistance to corrosion. It is noted that the treatment meets standard requirements. The preservation appears to be excellent. (See Appendix B.)

To reduce water-logging, all cracks, checks, and joints of wood plankings were caulked with oakum and then coated with coal-tar epoxy resin. All outside steel surfaces were first painted with primer red-lead (MIL-T-704) and then overcoated with black anti-fouling paint (MIL-P-19449).

The camel has two lifting and mooring eyes located approximately 10 feet from each end. In addition, a position maintaining device, not in the original design, was provided (Figure 1). The energy-absorbing characteristics of both hydro and pneumatic fenders are shown in Figures 2 and 3. It will be noted that each hydro-fender will absorb a maximum energy of 25 ft-tons as compared with 18 ft-tons (initial air pressure 24 lb/in²) for pneumatic fenders, assuming in both cases maximum pressure of 50 lb/in² which is the working strength of the rubber fenders. The impact load will not exceed a maximum allowable load of 40 tons on the ship's hull. Naval architectural characteristics are shown in Table I.

The camel design was reviewed by NCEL, CBC, and San Francisco Naval Shipyard. Reviewers included harbor pilots, designers, engineers and port facility operators. General comments were described by NCEL (1962)³ and BUDOCKS (1962)⁴. Two major modifications to the original design were made with the approval of BUDOCKS: (1) twenty-four 2-foot-long cylindrical precast sections of concrete were used to fill the ballast pipe in lieu of a solidly-filled concrete ballast, and (2) a position-maintaining device, as shown in Figures 1 and 8 was added to keep the camel in proper position under all tidal conditions.

The cost of the camel is approximately \$360 per foot of camel or \$68 per foot of berth. (See Appendix C.)

The bulkhead, rubber fenders, and ballast weights (concrete cylinders) were transported separately from the fabrication shop to the test site. The maximum dry-weight to be handled was estimated as 12 tons.

EXPERIMENTAL EQUIPMENT

Ship Velocity Meter

The approach velocity of the test ships is measured electronically by means of two mutually perpendicular probes, each employing a tachometer as sensor. As shown in Figure 4, one probe, a steel channel, is pushed back laterally by the berthing ship; thereby the velocity component normal to the wharf is measured continuously. This probe extends approximately five feet beyond the camel fenders prior to the berthing operations. The other probe is a bicycle-wheel fastened to the steel channel probe, thereby the velocity component parallel to the wharf is measured. The wheel is turned by the berthing ship. Since the velocity components in two directions are measured, the angle and speed of approach is readily determined.

Ship acceleration perpendicular to the wharf is measured by one accelerometer fastened to the ship's side near the transverse axis of the center of gravity of the ship. In addition an accelerometer is fastened to the ship-velocity measuring probe.

Energy Absorption

The energy absorbed by each of the pneumatic fenders is determined from measurements of the pressure exerted on each rubber fender. These, in turn, give the load-deflection history during impact. A sample calculation is provided in Figure 2. An air-pressure transducer in a water-proof housing is provided for each pneumatic fender. A special fitting serves to transmit the pressure to the pickup as well as to inflate the rubber fender.

The energy absorbed by each of the four water-filled rubber fenders is determined from load deflection characteristics (Figure 3) inferred from pressure measurements. The area of contact and deflection are related to the rate of flow by a calibration in which the discharge through the connecting tubes is directly related to the pressure measured.

Calibration was done using a pile testing facility (Hromadik, 1961⁵ and Figures 5 and 6). Three loads ranged from 12,500 to 50,000 lbs were applied at speeds of from 0.4 to 1.5 feet per second.

Water-level Variations

Fluctuations in the water surface are measured by a pressure pickup located on the harbor bottom.

Wind

Wind velocity is measured by two anemometers, one located nearby at the Tugs Office of Port Hueneme Harbor, another hand-held at the wharf.

Current

Currents are not measured and are believed to be insignificant.

Data Transmission and Recording

Signals from pickups are transmitted to an 18 channel direct-writing oscillograph through cables up to 500 feet long. The recorder is housed in a trailer maintained at constant temperature.

Visual Observations and Interviews

Visual observations include descriptions of environment, berthing ship characteristics, and berthing procedures. In addition, the ship's captain, port pilot and other docking personnel are interviewed.

A sample Field Inspection Worksheet completed for "SS Alaska Bear" is shown in Figure 7.

PROCEDURE

Two camels were fabricated at NCEL and installed on March 8, 1963 at Wharf No. 3 of the Port Hueneme Harbor, using a mobile crane, with a clear spacing of approximately 100 feet. Figures 8 and 9 show the camels during installation and operation, respectively. Figure 10

shows the general plan and profile at the test site.

During each berthing, the pressures exerted on the rubber fenders, lateral and longitudinal components of ship approach velocity, ship acceleration and water-level variations and wind velocity are measured and recorded (Figure 15). The average period of recording varies from 10 to 20 minutes. After the ship is berthed, the ship's captain, harbor pilot, and port operators are interviewed. Usually measurements are not made at the time of ship-departure.

RESULTS

Excitations

a. Wind, wave, and currents

Wind velocities from 5 to 45 knots were recorded. 60% of the time the wind was from the NW direction. This is 45° off port beam of the wharf face. Details of wind data are given in Table II.

Water-level variations during testing were insignificant with the exception of a great swell of unknown period and amplitude on March 11, 1963.

Only occasional tug-induced surface currents were significant.

b. Berthing Ships

Fifteen ships ranging in size from 8,000 to 20,000 tons displacement, made contact with the test camels over a period of four months (Table II). All ships berthed at Wharf No. 3 with the assistance of two tugs. In most cases, the ship initially was brought in at an angle, then swung beam-on the wharf and finally was pushed slowly to berth. In some instances, the ships were moved longitudinally soon after their first contact with the camels. Ship approach velocity was 0.1 to 0.75 foot per second. Typical measured ship approach velocities are shown in Figure 11. The direction of ship motion varied from 0° to 90° port beam relative to the wharf face. A summary of environments, berthing-ships characteristics, berthing procedures and responses (impact load and energy absorption), and comments of ships' captains and others is given in Table II.

Hydrodynamic masses and kinetic energy were computed using measured ship velocity, acceleration, and the known ship characteristics. The hydrodynamic mass varied from 2.98 to 3.46 times the ship's mass (Figure 15). The kinetic energy generated by the berthing ship varied from 3 to 73 ft-tons.

c. Biological Excitation

Marine growth which were active in the harbor include: barnacles, mussels, tube worms, bryozoa, hydroids, tunicates, sponges, Bankia species, teredo species, limnoria, tripunetata, and algae.

Response

a. To Wind, Wave and Current

The kinetic energy resulting from winds, waves, and currents was considered insignificant as compared with that generated by the berthing of the ship. However, these environmental forces caused both ship and camel to heave, pitch, roll, surge and sway. When the camels were unoccupied, the surge and sway motions were considerable under severe sea conditions. Resonance motion of the camels due to waves of the same period of oscillation was noted. During an examination of the floating camel in late May 1963, it was found that the unsubmerged portions in contact with the fender piles have worn as shown in Figure 13. There was no wear on the fender piles since the piles were well protected with steel strips. The north camel had a higher degree of wear than the south camel because of higher waves.

b. To Berthing Ship

The total load exerted by the rubber fenders was computed indirectly from the pressures measured. It varied from 4.2 to 24.6 long tons. The total kinetic energy absorbed was obtained from the summation of the energy absorbed by each individual rubber fender in contact with the berthing ship. It varied from 1.5 to 17 ft-tons which is from 4% to 42% of minimum designed capacity of the two camels. The energy-absorbing data is shown in Table II and Figure 15. A sample spectral analysis of measured pressures was made and the significant, average and highest one-tenth of energies absorbed were determined accordingly (Figure 14).

The test results showed that the pneumatic ship-fenders normally absorbed more energy than the hydro-fenders. The reason is that the hydro-fenders are capable of absorbing much greater kinetic energy only when the impact has a high-rise time. Attempts were made to have the ships berthed at higher approach velocity but this idea was not acceptable to the pilots for safety reasons. However, it was realized from the characteristics curves (Figure 3) that the hydro ship-fenders absorb more energy under severe berthing conditions.

The captains of the ships reacted favorably, generally. The camels performed well and damped ship motions during winds with sustained speeds of 20 knots and gusts to 45 knots. The camels created serious cargo-handling problems according to the Port Services Officer and the Marine Terminal Superintendent since the extent to which the camels hold the ships off the wharf tends to make loading or unloading unsafe when cargo has to be handled by equipment on board the ship. No problems were encountered when serving passenger ships or cargo ships of modern design.

There were no significant damages to the rubber fenders either by excessive impact or by large ship protuberances. The only accident which happened during the tests was the breakage of a mooring bead (hook-ring) on top of a pneumatic fender. The cause of the minor damage was unknown. It was very possible that the damage was made by a working barge. The cost to repair the damage was \$50. In addition, two pneumatic fenders have developed air leakage. Remedial work is in progress.

d. To Corrosion and Biological Excitation

The corrosion and biological effects on the camels were minor. Heavy marine-growth (algae) was found at the water-line of the fenders, particularly the hydro-fenders. Barnacles and bryozoa were found on the camel bulkhead and the hydro-fenders (Figures 12 and 13). They caused no operational trouble. Detailed comments are given in Appendix D.

FINDINGS

1. Excitations

a. Winds of 5 to 45 knots from the northwestern direction were encountered 60% of the time. This is 45° off port beam of wharf face.

b. Waves and currents were negligible.

c. Fifteen naval and merchant ships of 8,000 to 20,000 tons displacements made contact with the camels over a period of four months.

d. Ship approach velocity was 0.1 to 0.75 foot per second.

e. Ship excitation was slight due to tugs' assistance.

f. The direction of approach was approximately normal to the wharf face (broadside berthing) at the first contact with the camel.

g. The kinetic energy generated by the ships was estimated to be from 3 to 73 ft-tons.

h. Marine growth such as barnacles, bryozoa, clams, tunicates, and algae were active in the harbor.

2. Response

a. The kinetic energy generated by wind, wave, and current was insignificant.

b. Resonance motion of the camels resulted in some wear on contact areas between camel and fender piles.

c. Impact load on the camel due to ship-impact varied from 4.2 to 24.6 long-tons.

d. Kinetic energy absorbed varied from 1.5 to 17 ft-tons. The cushion effect was generally good.

e. Light cover of barnacles, bryozoas, and algae on the camel caused no operational trouble.

f. After serving fifteen ships, only superficial damage was found. The fittings on two pneumatic fenders failed, and the mooring bead (hook-ring) of one pneumatic fender was broken by an unknown barge.

3. Operational Features

a. Ship captains generally showed enthusiasm.

b. The Port Services Officer and the Marine Terminal Superintendent complained that the camel holds ships too far off dock for service by on-board booms.

c. Ships berthed broadside at the camel safely and comfortably. No jerks or bumps were felt on board the berthing ships.

d. The camel was helpful in reducing ship motion when berthing was subject to swell and wave action.

e. The initial air-pressure of 12 lb/in² inside the pneumatic fenders apparently provided satisfactory energy-absorption and did not dent the ship's hull. The rubber fenders have adequately sustained the lateral, longitudinal, and torsional forces induced by ships.

CONCLUSIONS

1. After four months of operation with fifteen ships served, the camel is considered satisfactory, except for the creation of cargo-handling problems.

2. Impact loading induced by the ships is relatively light. The minimum total energy absorption capacity of the camel has not been utilized.

3. Tests need to be continued for at least one more year to provide meaningful evaluation of the camel. This will be done in FY-64.

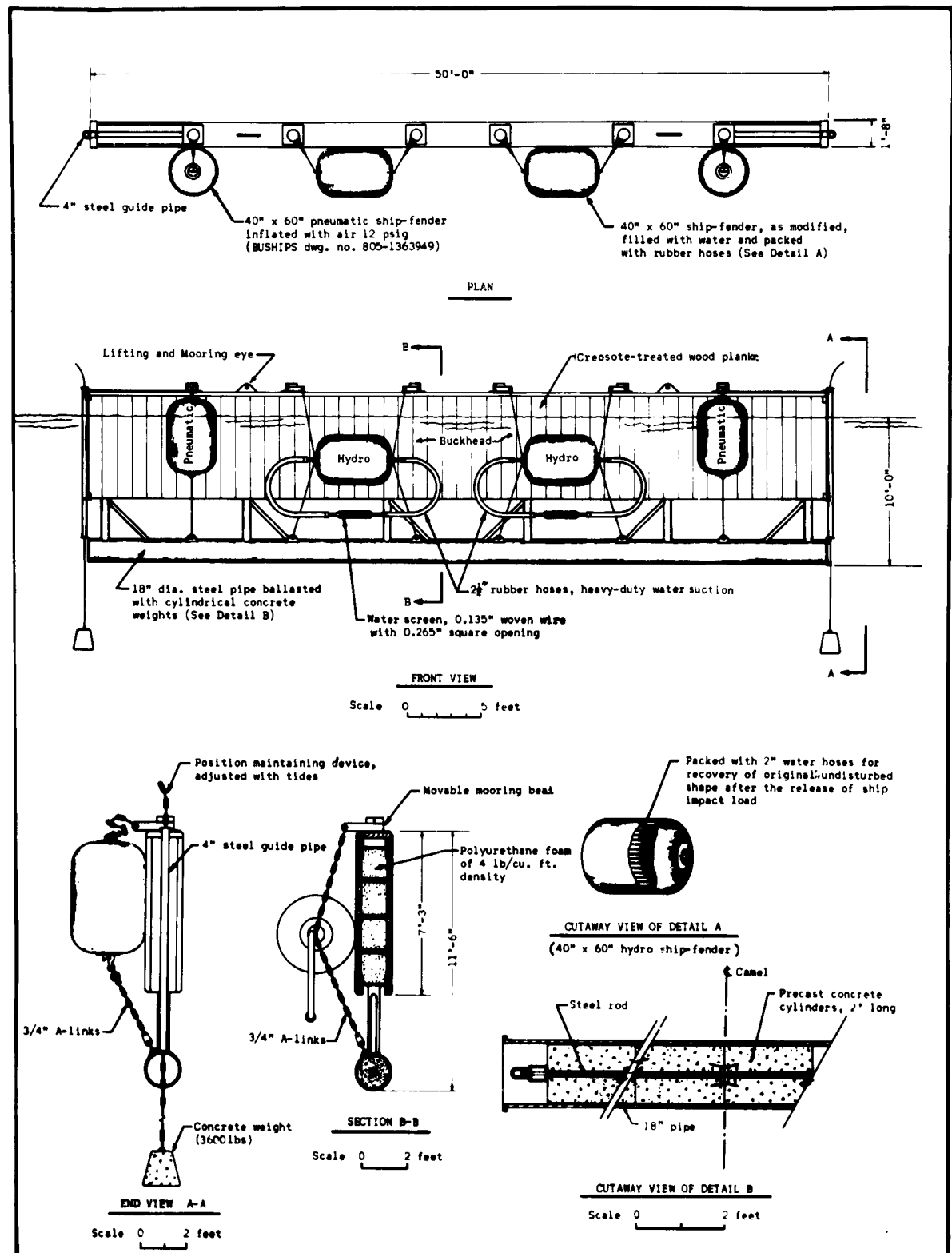
ACKNOWLEDGEMENTS

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Mr. Dale H. Johnson, Instrumentation Division and Mr. R. O. Doty, Design Division, designed the ship velocity meter. Mr. Johnson and Mr. J. C. Quigley, Instrumentation Division assisted in installation and operation of the instruments. Messrs. A. H. Cannon, G. L. Cappedge, J. P. France, and L. J. Temple, and others were active in the fabrication of the camel. Mr. C. V. Brouillette, Chemistry Division, assisted in evaluation of the effect of marine growth and corrosion. Mr. T. Roe, Jr., Chemistry Division and Mr. J. W. Chapin, Process Division assisted with the creosoting technique. Members of the Design Division assisted in data-reduction and preparation of some illustrations in the report. The special assistance of the members of the Photographic Division in reproduction of the illustrations is gratefully acknowledged. All persons listed are on the staff of NCEL. Professor R. O. Easton also furnished comments.

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NOTE: This figure was prepared based on Y & D Dwg No. 946116 and 946117, as modified by NCEL.

Figure 1 Hydro-pneumatic Energy Absorbing Camel

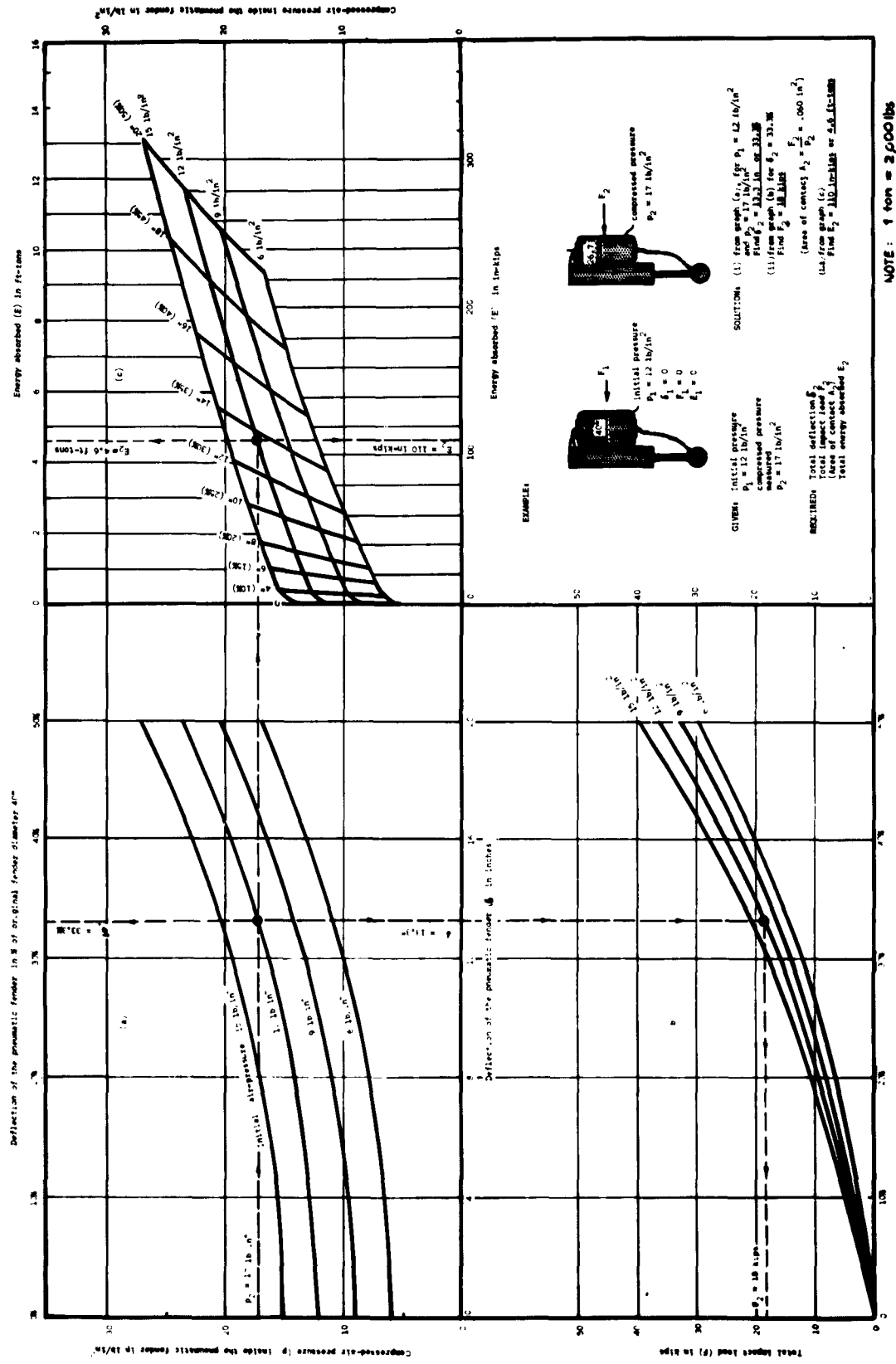
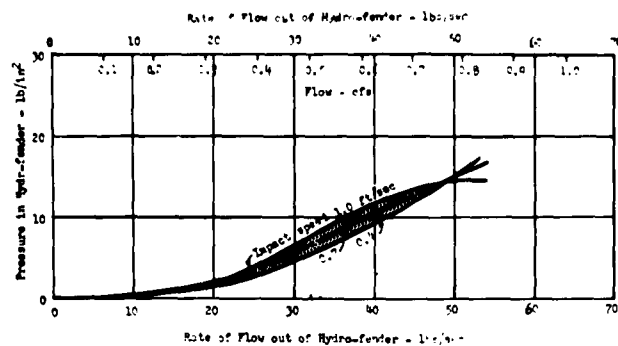
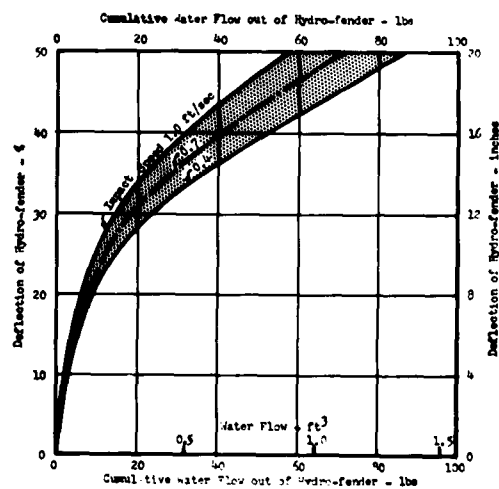


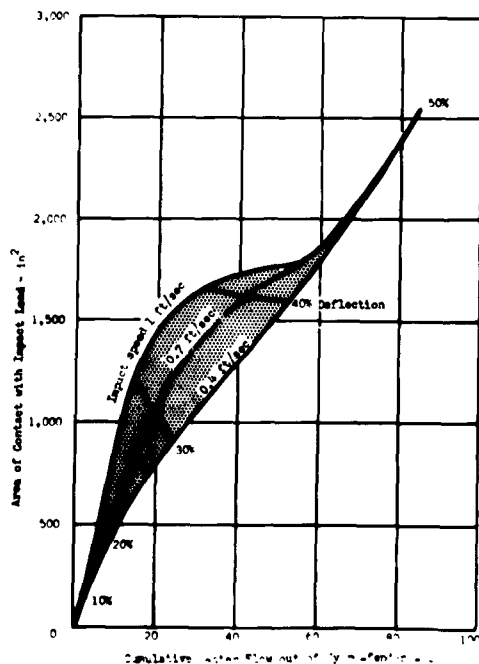
Figure 2 Energy Absorbing Characteristics of Pneumatic Rubber Ship-fender



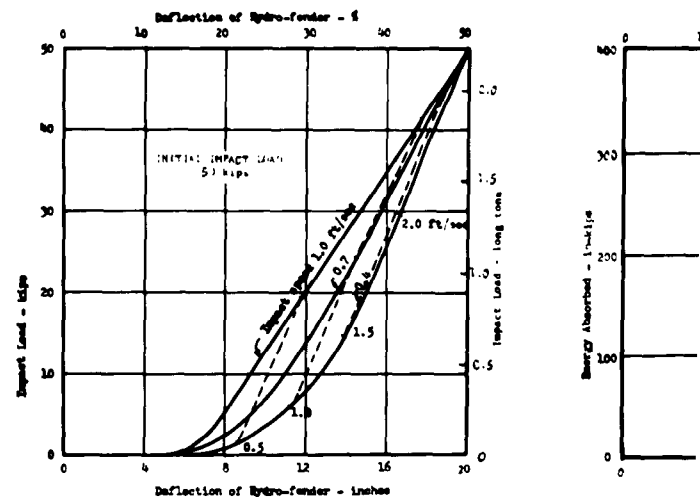
(a) Pressure - Water Flow Relationship



(b) Water Flow - Deflection Relationship

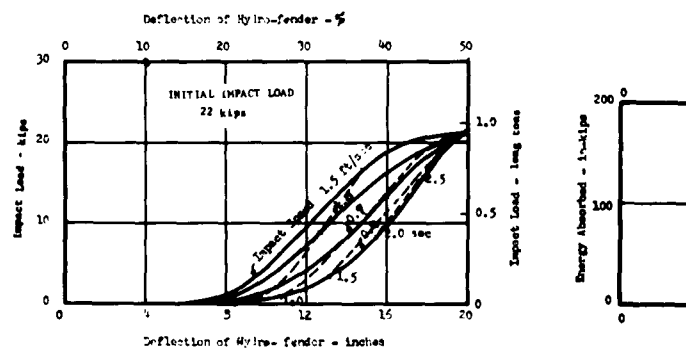


(c) Deflection - Contact Area Relationship



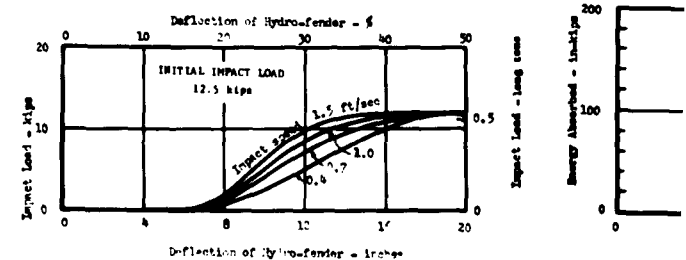
(d) Load - Deflection Characteristics (Initial Impact Load = 50 kips)

(g) Energy Charac (Initi



(e) Load - Deflection Characteristics (Initial Impact Load = 22 kips)

(h) Energy Chara (Initi

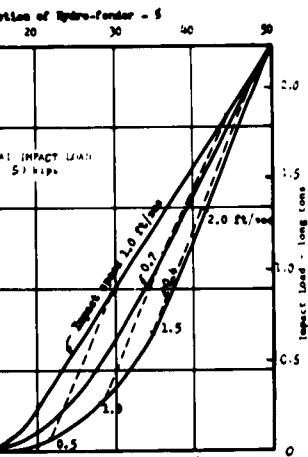


(f) Load - Deflection Characteristics (Initial Impact Load = 12.5 kips)

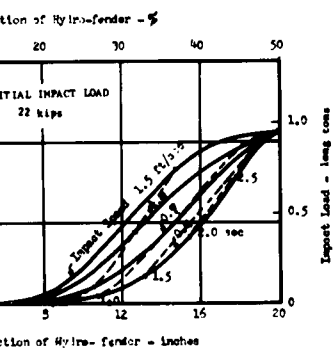
(i) En (Cha (In

Figure 3. Energy-Absorbing Hydro Rubber S

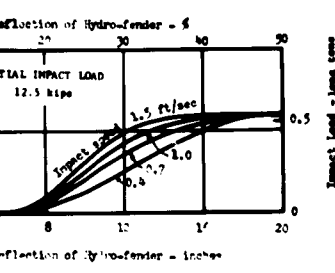




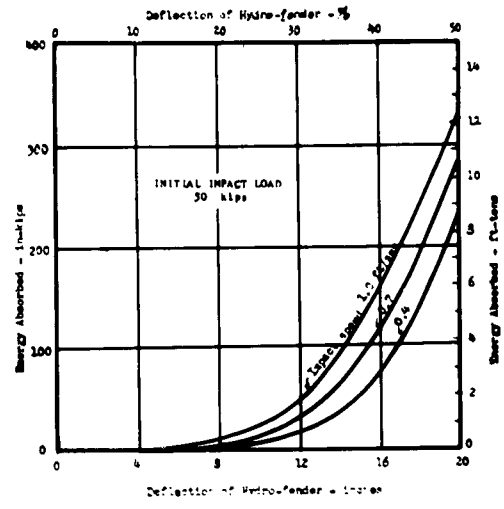
(g) Deflection Characteristics of Hydro-fender (Initial Impact Load = 50 kips)



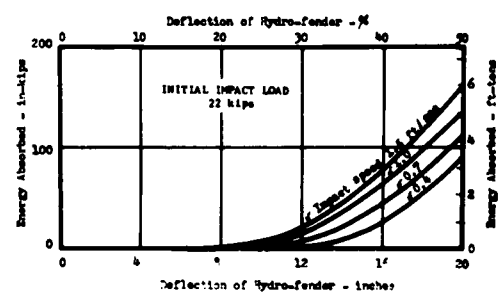
(h) Deflection Characteristics of Hydro-fender (Initial Impact Load = 22 kips)



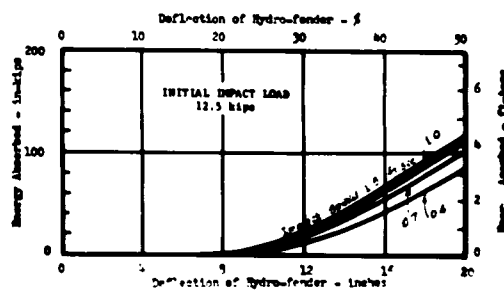
(i) Deflection Characteristics of Hydro-fender (Initial Impact Load = 12.5 kips)



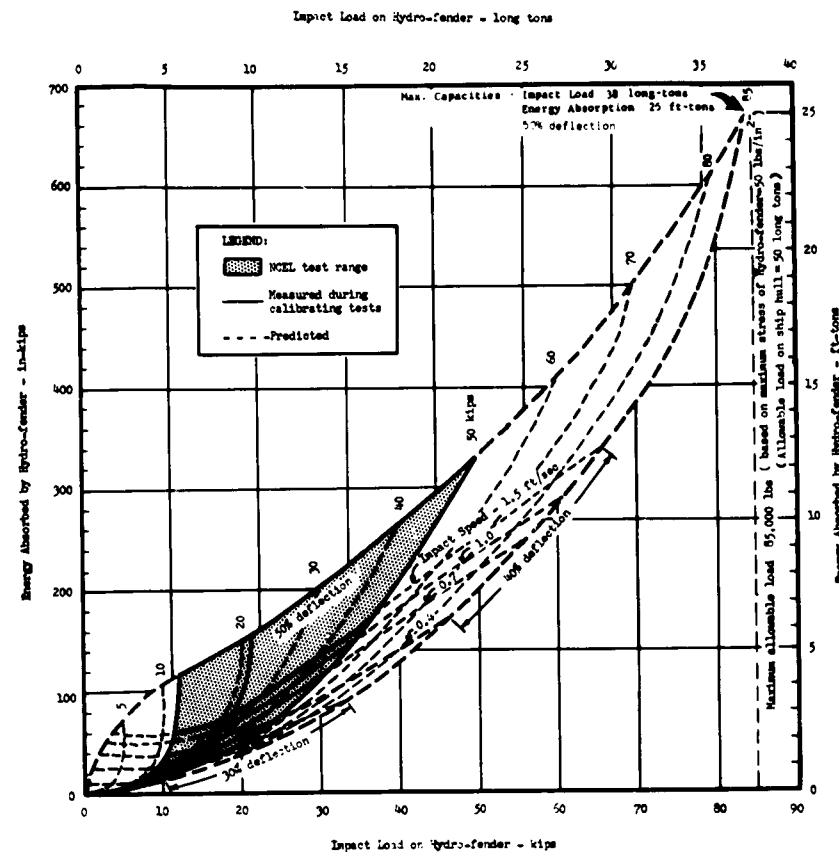
(g) Energy Absorption - Deflection Characteristics of Hydro-fender (Initial Impact Load = 50 kips)



(h) Energy Absorption - Deflection Characteristics of Hydro-fender (Initial Impact Load = 22 kips)

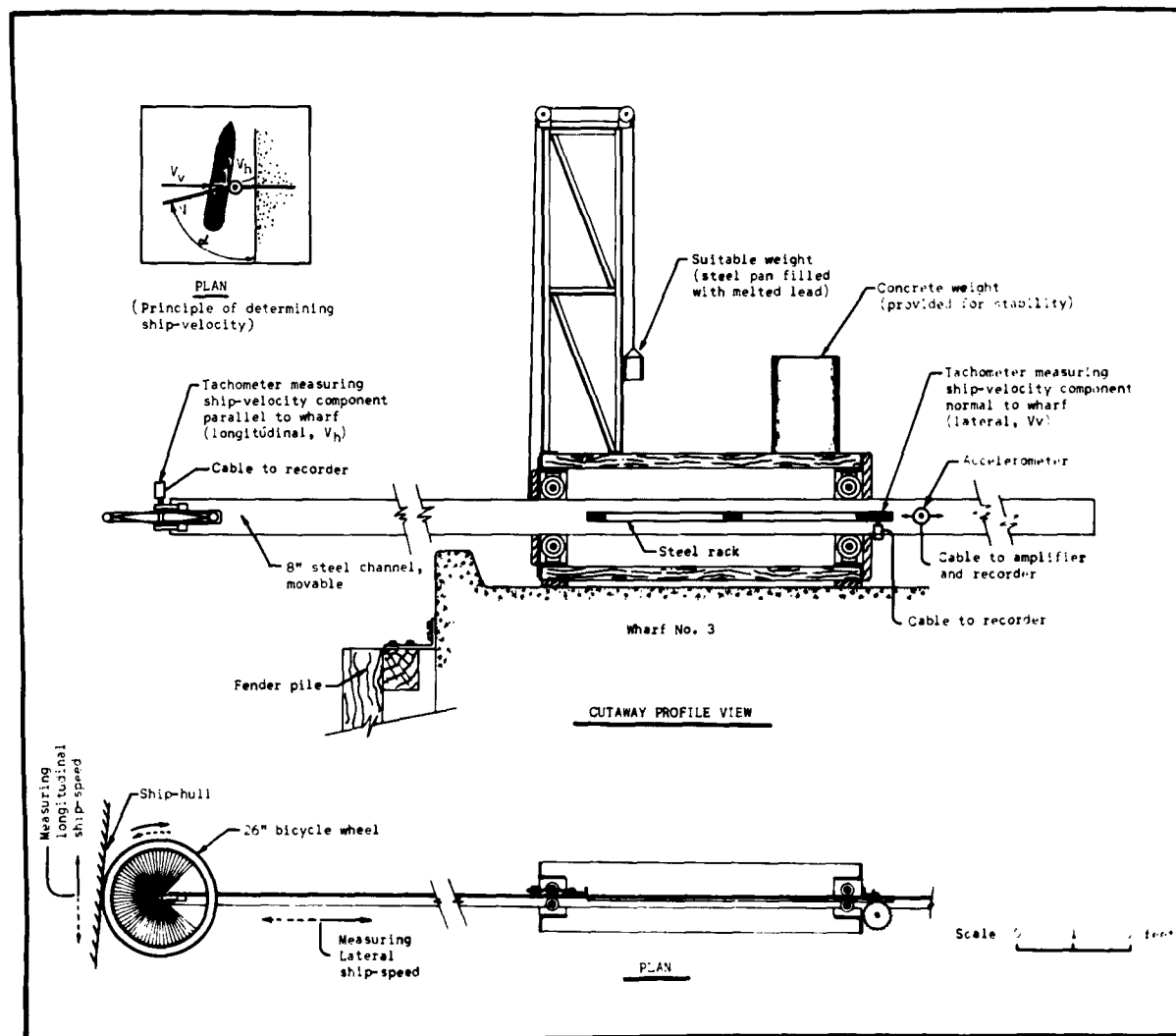


(i) Energy Absorption - Deflection Characteristics of Hydro-fender (Initial Impact Load = 12.5 kips)



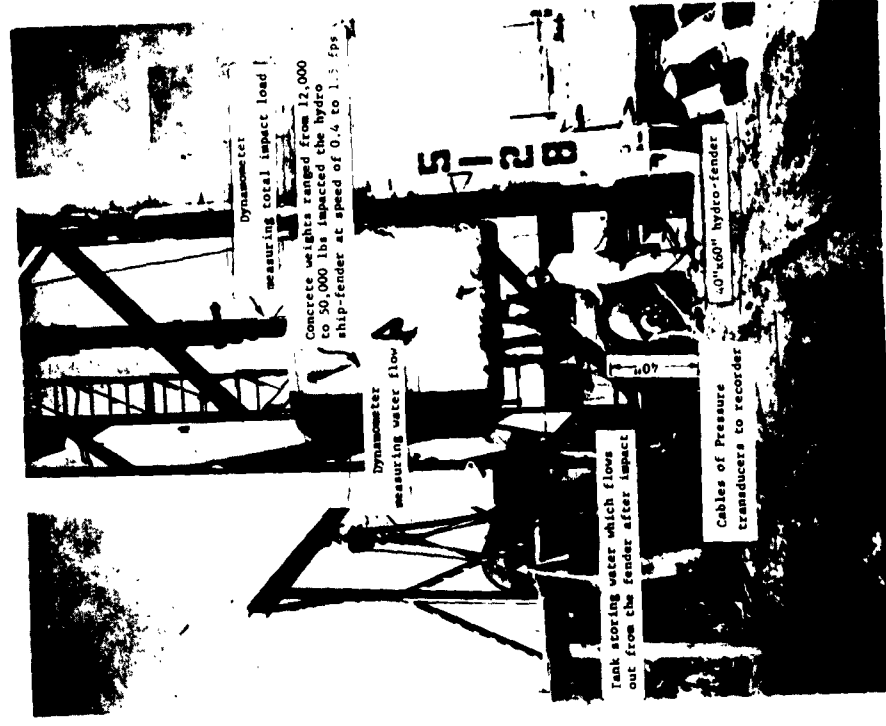
(j) Energy - Absorbing Characteristics of a 40" x 60" Hydro Ship-Fender

NOTE : 1 long-ton = 2240 lbs

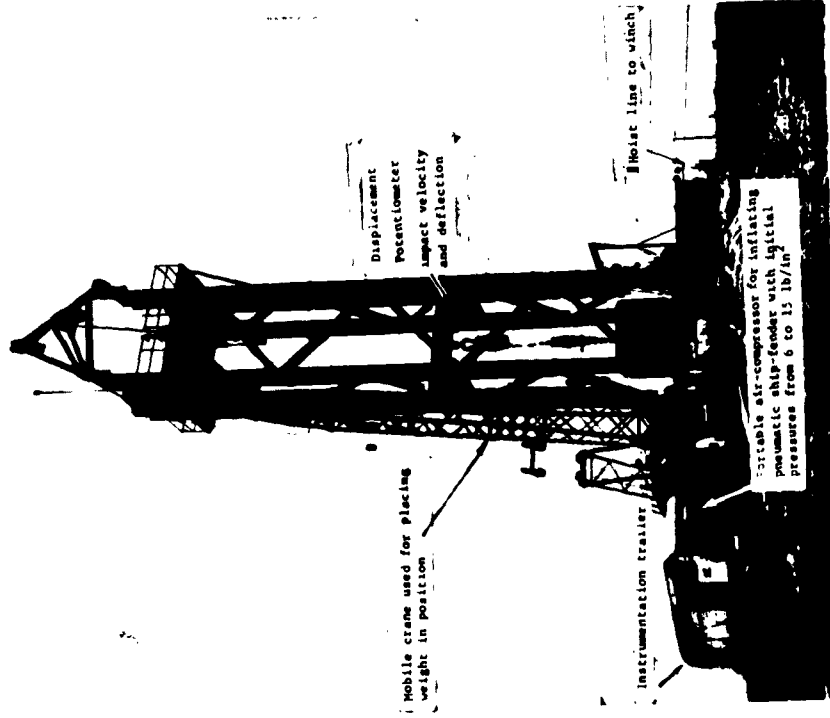


NOTE: This figure was prepared based on NCEL Dwg No. 62-34-1F and 62-34-2F, as modified.

Figure 4 A Ship-Velocity Measuring Device



(b) Concrete weight being elevated ready for testing of hydro and pneumatic rubber ship-fenders



(a) Long-pile testing tower used for calibrating

Figure 5 Testing Facilities Used for Calibrating Both Hydro and Pneumatic Rubber Ship-fenders (See also Figure 6)



(a) The hydro-fender deflected to 20" from original 40" diameter

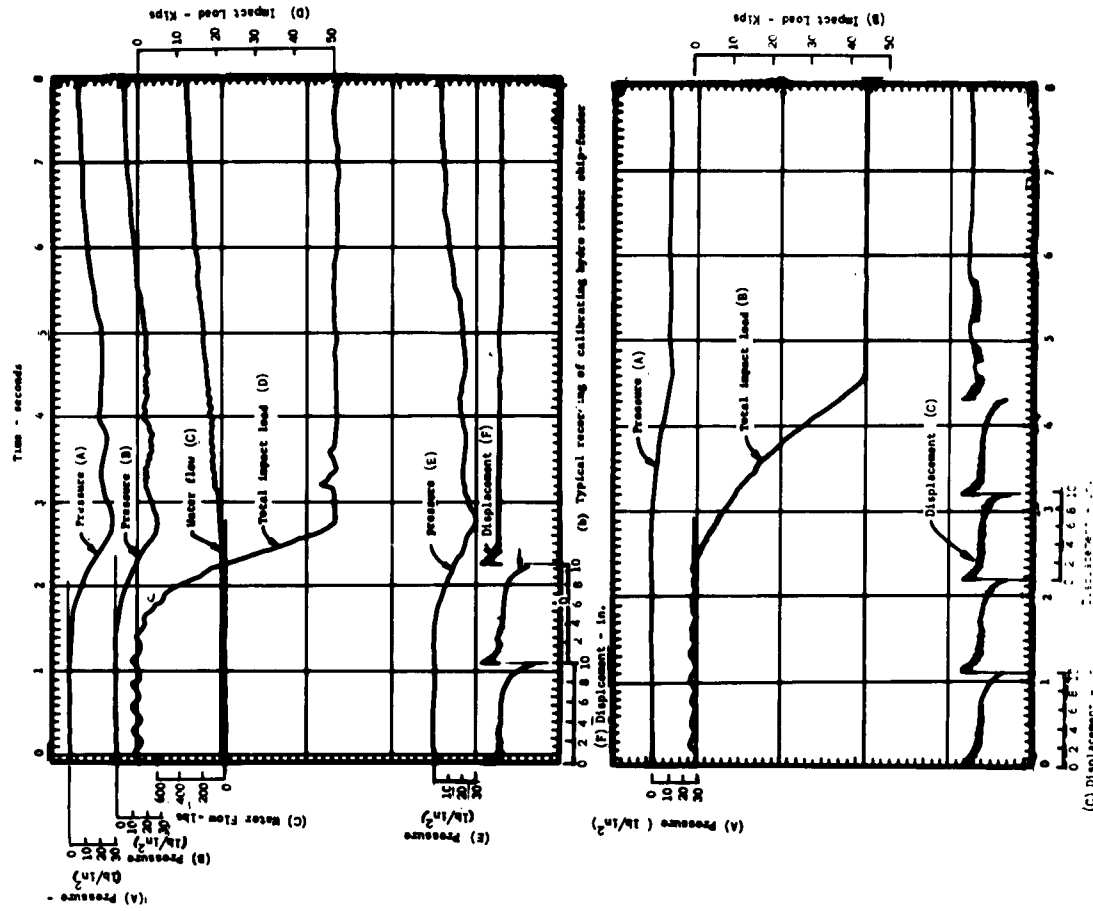
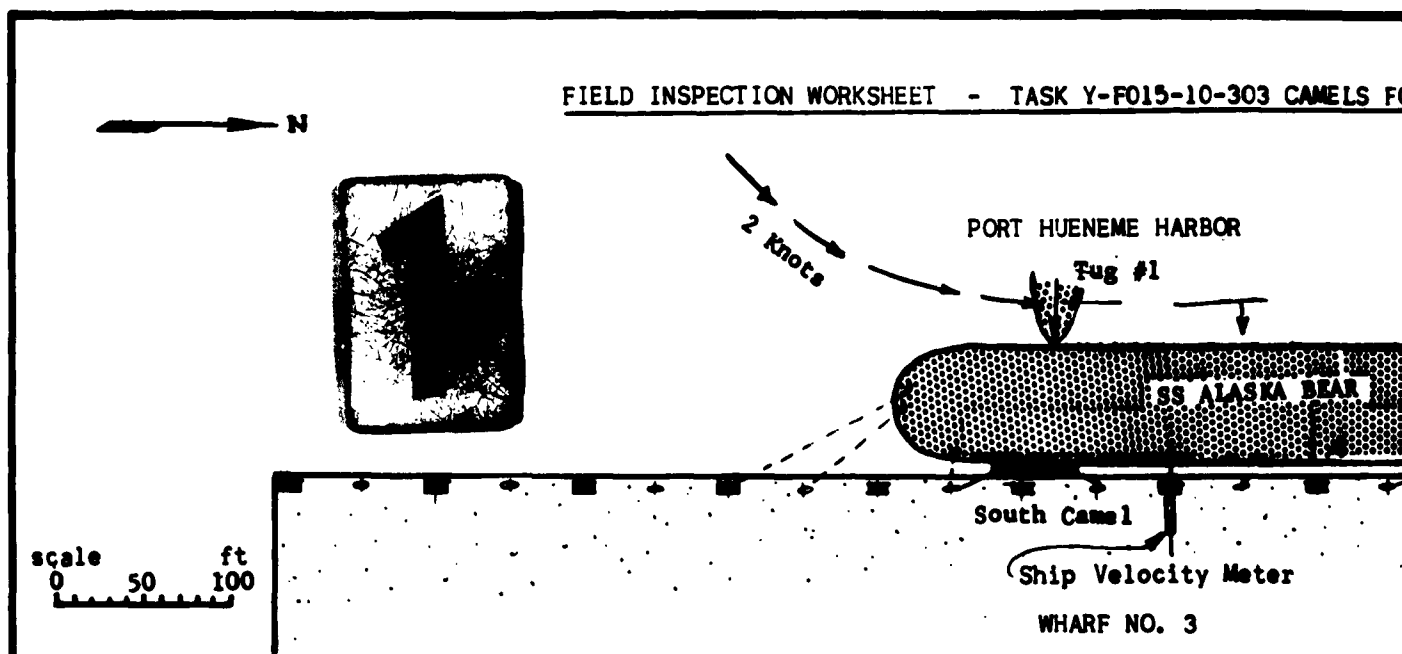


Figure 6 Testing Facilities Used for Calibrating Both Hydro and Pneumatic Rubber Ship-fenders (See also Figure 5)

FIELD INSPECTION WORKSHEET - TASK Y-F015-10-303 CAMELS FC



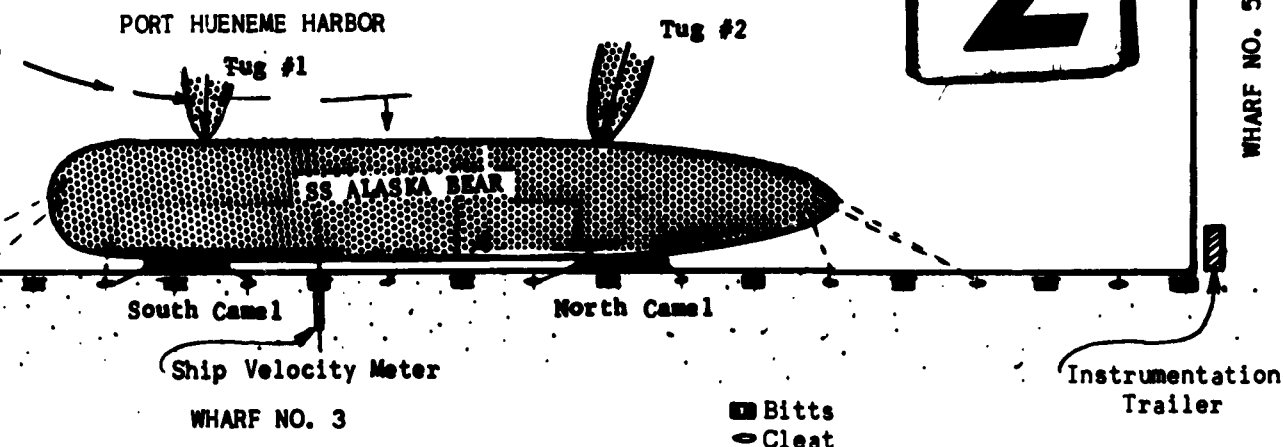
ENVIRONMENT		BERTHING SHIP CHARACTERISTICS
<p><u>Wind:</u> Speed 6mph Direction: 20-25°</p> <p><u>Wave:</u> <input checked="" type="checkbox"/> Calm <input type="checkbox"/> Moderate <input type="checkbox"/> Rough</p> <p><u>Current:</u> <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No</p> <p><u>Tug-made Wave:</u> <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No</p> <p>Tug speed: - knots</p> <p>Angle of approach - degrees</p> <p><u>Small:</u> <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No</p> <p><u>Tide:</u> <input type="checkbox"/> High Gage +2 ft</p> <p><input type="checkbox"/> Mean</p> <p><input checked="" type="checkbox"/> Low</p>		<p><u>Names:</u> Ship: Alaska Bear Captain David L.</p> <p><u>Type:</u> Pacific Far East Line, Inc.</p> <p><u>Displacement:</u> Full 15,200 tons</p> <p>Berthing 8200 tons</p> <p><u>Length:</u> 455' 3"</p> <p><u>Beam:</u> 62'</p> <p><u>Draft:</u> Bow 10.5 ; Stern 22.5</p> <p>Mid-draft 28' 6 3/4" (full)</p>
GENERAL COMMENTS	SHIP CAPTAIN	<p>(1) The distance between the dock and ship berthed is considered too far but this would be satisfactory.</p> <p>(2) The normal boom capacities ranged from 5 tons to 50 tons for large boom. Small booms are not adequate.</p> <p>(3) The simple-log camel is considered adequate for most merchant ships. There is no problem with the log camel.</p> <p>(4) The high-pressure inside the rubber fenders might dent the ships hull.</p> <p>(5) It will be possible to break the bags by pin-pointing and longitudinal forces, (observed).</p> <p>(6) The test camels have the advantage of distributing impact load to fender piles but the test camels are not as effective as the log camel.</p> <p>(7) Consideration should be given to securing the rubber fenders directly to the fender piles.</p>
	PILOT AND OTHERS	<p>Capt. Fosse commented: (1) The cargo ship is too far away from dock for satisfactory berthing.</p> <p>(2) The rubber fenders will be subjected to tearing loose by barges.</p> <p>(3) The half-pipes welded on ship-hull (from scupper to the bow) are not adequate.</p> <p>(4) The test camels would work well in large harbor basins.</p> <p>Capt. Swanson commented: (1) There is a law that the maximum distance between dock and ship is 100 feet.</p> <p>(2) Rubber tubes hanging on fender piles would be better than the log camel.</p>
	SUMMARY	<p>Capt. Parker is very cooperative, and pleasant to work with. It seems that the berthing was very careful. No wave and inertia impact observed. Only four bags of cement were used.</p>

Figure 7 A Sample Field Inspection Worksheet

2

Date: 23 April 1963 (0635)

Name of Inspector: T. T. Lee



Instrumentation	
(check <input checked="" type="checkbox"/> if working)	
Air Bag Pressure Transducers	<input type="checkbox"/> #1 <input type="checkbox"/> #2 <input type="checkbox"/> #3 <input type="checkbox"/> #4
Water Bag Pressure Transducers	<input type="checkbox"/> #1 <input type="checkbox"/> #2 <input type="checkbox"/> #3 <input type="checkbox"/> #4
Ship Velocity:	<input checked="" type="checkbox"/> Longitudinal <input checked="" type="checkbox"/> Lateral <input checked="" type="checkbox"/> Acceleration
Ship Acceleration	<input type="checkbox"/> #1 <input type="checkbox"/> #2 <input type="checkbox"/> #3
Wave Gage	<input checked="" type="checkbox"/>
Wind Gage	<input checked="" type="checkbox"/>
Current	<input type="checkbox"/>

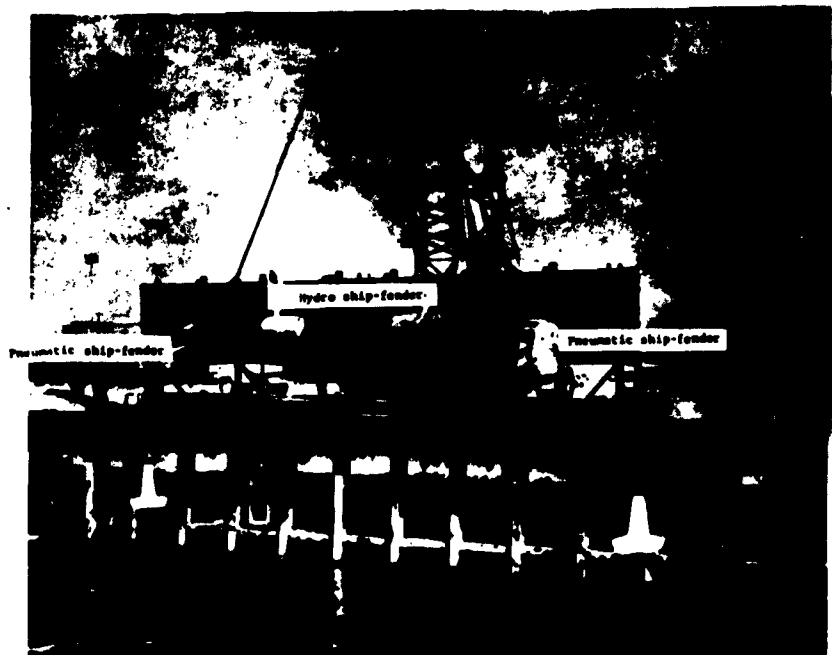
BERTHING SHIP CHARACTERISTICS	BERTHING PROCEDURES
Ship: <u>Alaska Bear</u> Captain: <u>David L. Parker</u> Company: <u>Pacific Far East Line, Inc.</u> Displacement: <u>Full 15,200 tons</u> <u>Berthing 8200 tons</u> Length: <u>455' 3"</u> Breadth: <u>62'</u> Draft: <u>Bow 10.5 ; Stern 22.5</u> <u>Mid-draft 28'6 3/4" (full)</u>	Tug Assistance: No of Tugs: <input type="checkbox"/> None <input checked="" type="checkbox"/> Tugs Nominal Power of Tug: <u>1030 hp/tug</u> Location of Tugs: (see sketch above) Ship Approach Angle (Approx.): <u>45°</u> then <u>0°</u> Ship Approach Velocity: <u>2 knots (angle)</u> Ship-Leaving Velocity (Approx.): Part of Ship Contacted Camel First: <input type="checkbox"/> Bow <input type="checkbox"/> Stern <input checked="" type="checkbox"/> Broadside Durations: Berthing: From <u>6:30 am</u> to <u>16:30 pm</u> Berthed: <u>10</u> hours

ched is considered too far but this would not present any serious problem in cargo-handling.
 ns to 50 tons for large boom. Small boom capacity may be below 5 tons as designed.
 e for most merchant ships. There is no need for special-type camels such as the test camels.
 s might dent the ships hull.
 in-pointing and longitudinal forces, (obstructions on shipside) especially by inexperienced naval captains.
 istributing impact load to fender piles but are expensive, waste of money. No camel would stop accidental ship-impact
 e rubber fenders directly to the fender piles.

too far away from dock for satisfactory self-loading and unloading operations.
 will be subjected to tearing loose by barges.
 ded on ship-hull (from scupper to the water line) would tear the rubber fenders when ship surges.
 ould work well in large harbor basins.
 hat the maximum distance between dock and ship should not exceed 36".
 ing on fender piles would be better than the test camels.
 to work with. It seems that everyone complains that the distance of 5 feet from dock to shipside is too far
 ertia impact observed. Only four bags contacted the ship. (See sketch above)

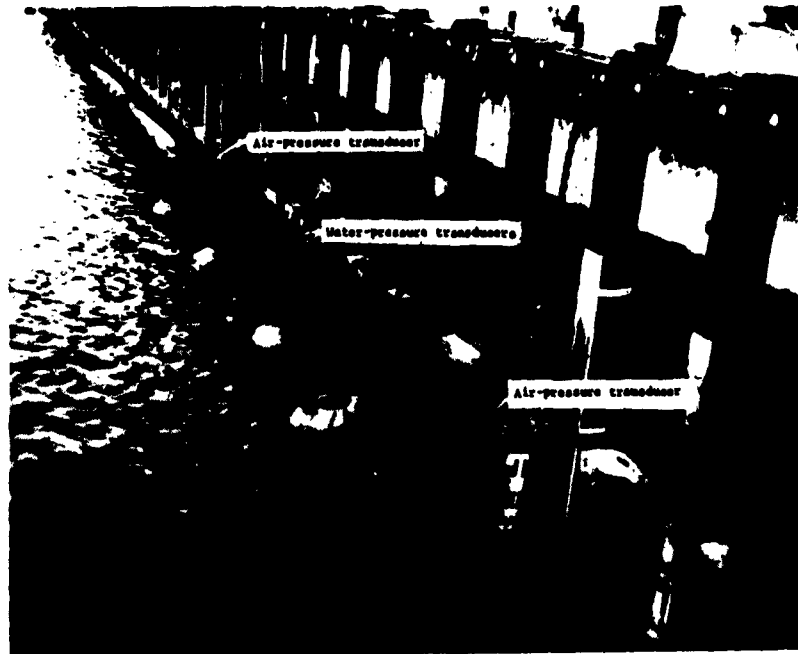


(a) A Single-log Camel Being Removed

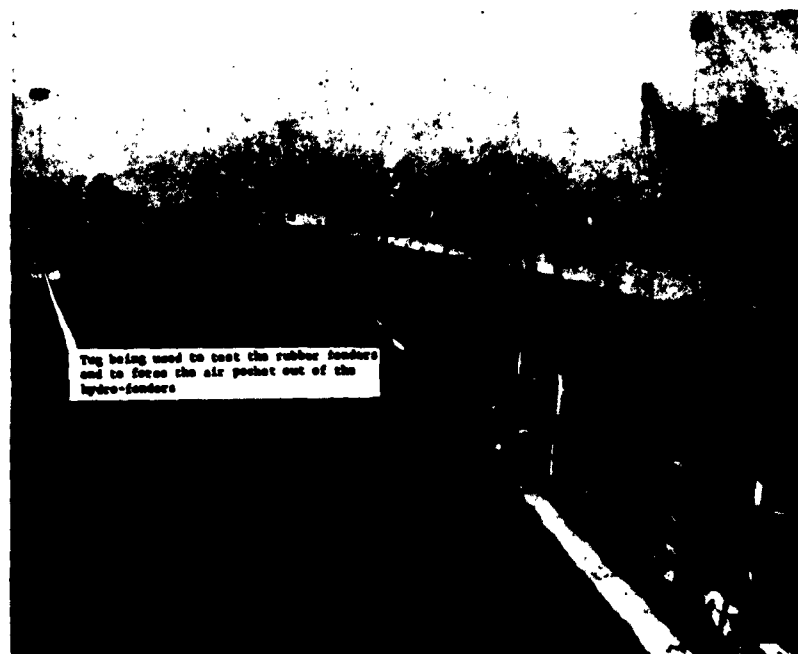


(b) A Hydro-pneumatic Camel Being Installed

Figure 8 Installation and Operation of a Hydro-pneumatic Camel at Wharf No. 3, Port Hueneme Harbor, Calif. (See also Figure 9)



(a) Close View of a Hydro-pneumatic Camel Placed in Testing Operation



(b) A Pair of Hydro-pneumatic Camels Ready for Trail Operation

Figure 9 Installation and Operation of a Hydro-pneumatic Camel at Wharf No. 3, Port Hueneme Harbor, Calif. (See also Figure 8)

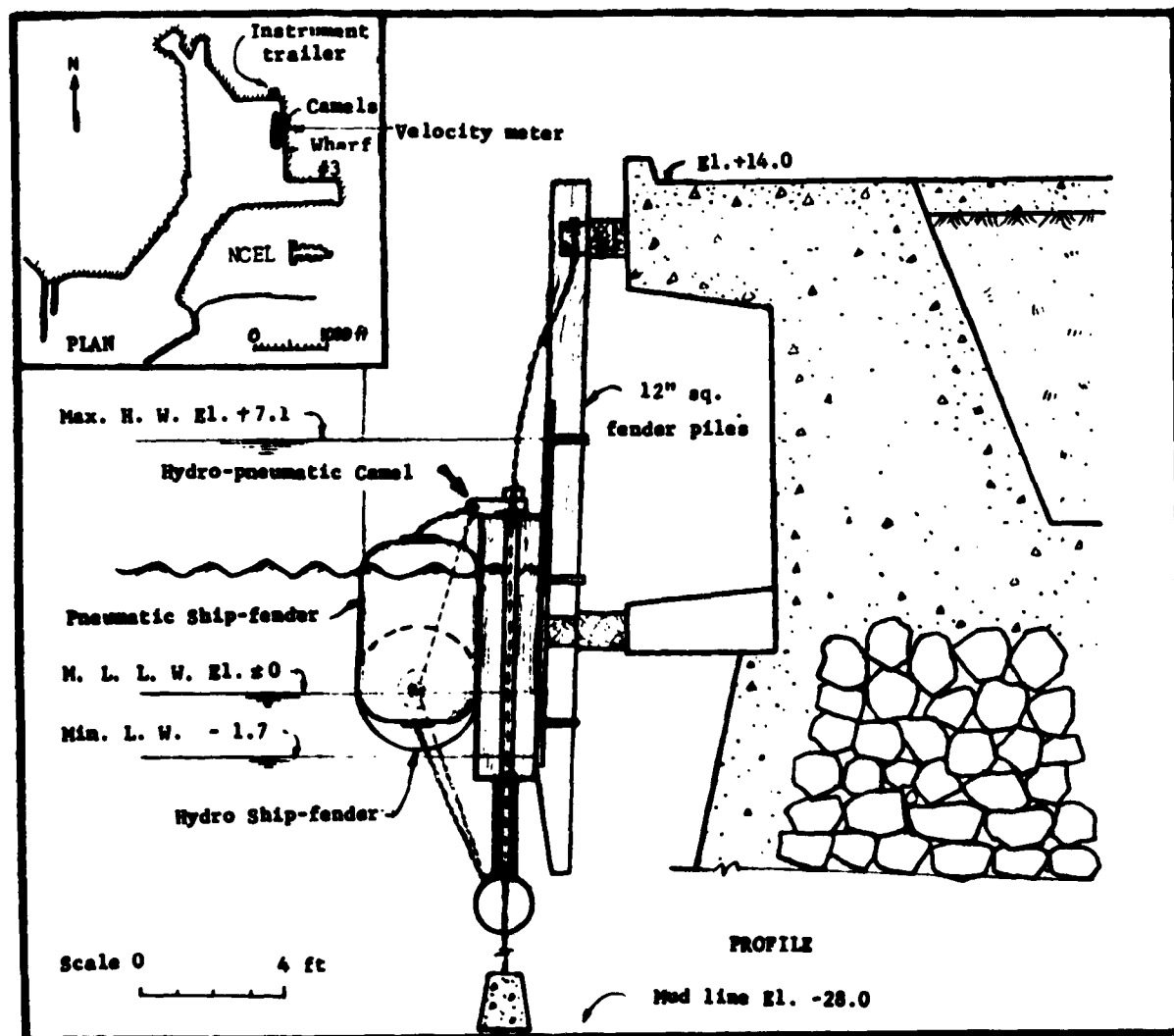


Figure 10 General Plan and Profile of the Test Site -
Wharf No. 3, Port Hueneme Harbor, California

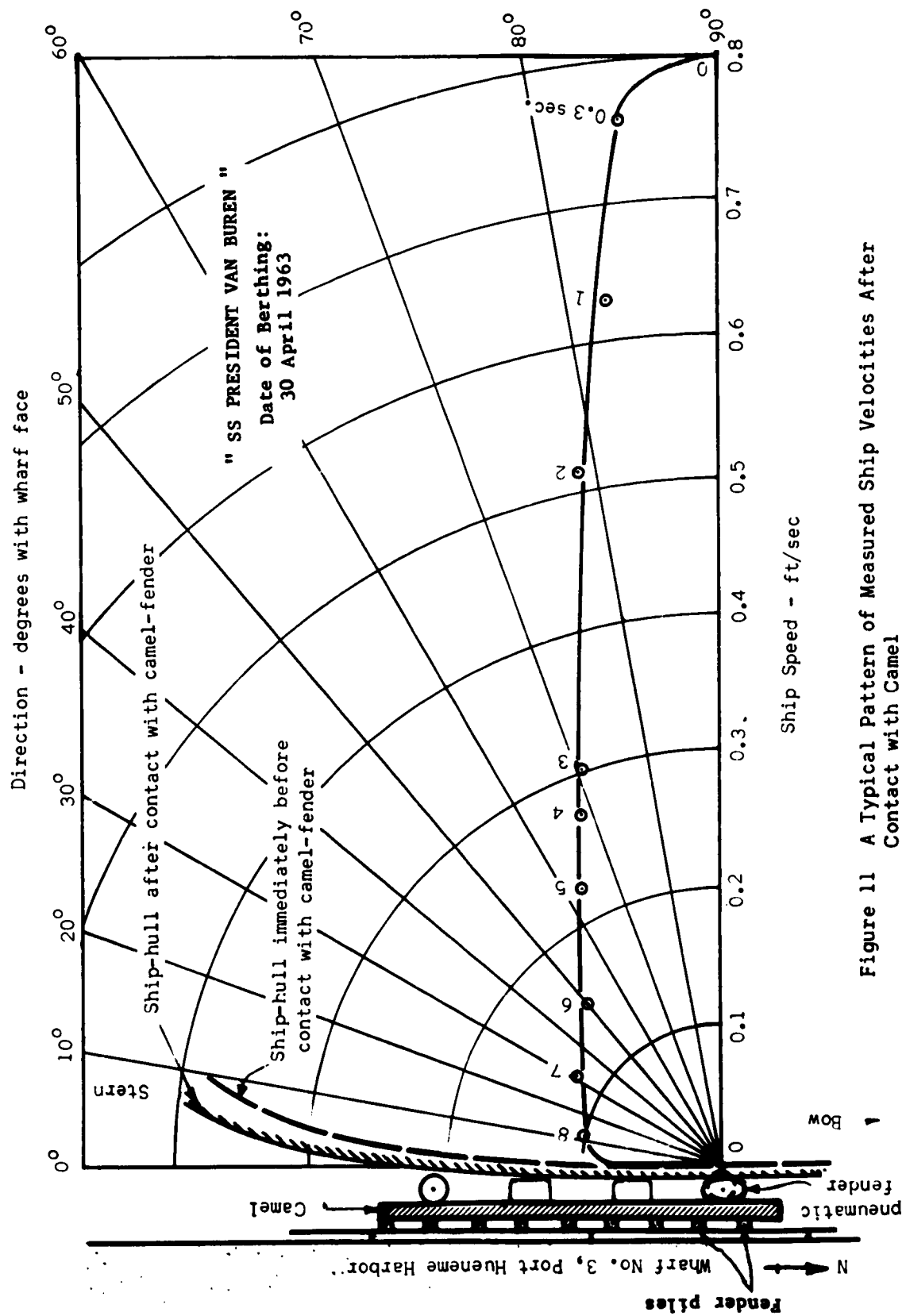


Figure 11 A Typical Pattern of Measured Ship Velocities After Contact with Camel



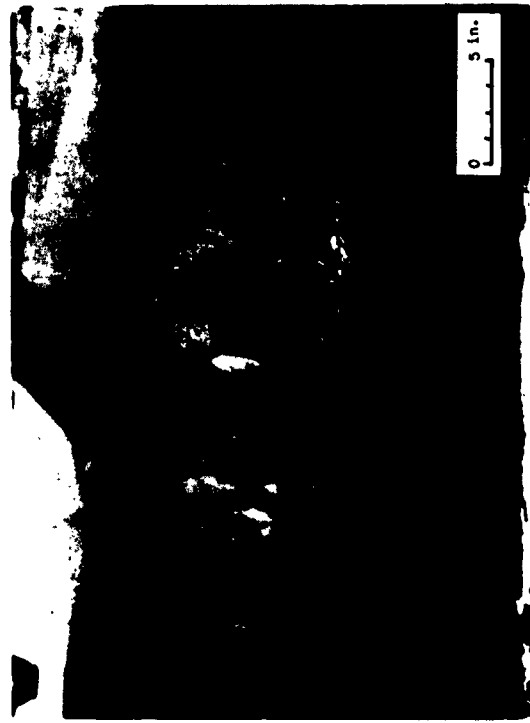
(a) Front View



(b) Rear View



(c) Close View of Hydro Ship-fender



(d) Corrosion of the Ballast Pipe

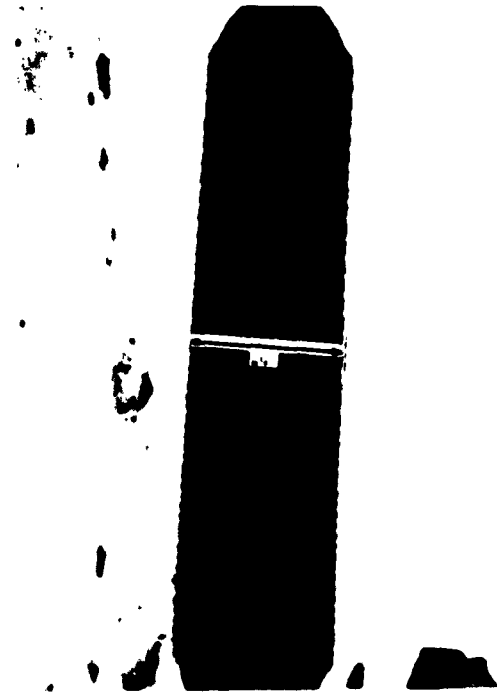
Figure 12 Corrosion and Marine-Growth Characteristics of Hydro-pneumatic Camel
(three months' immersion) (See also Fig. 13)



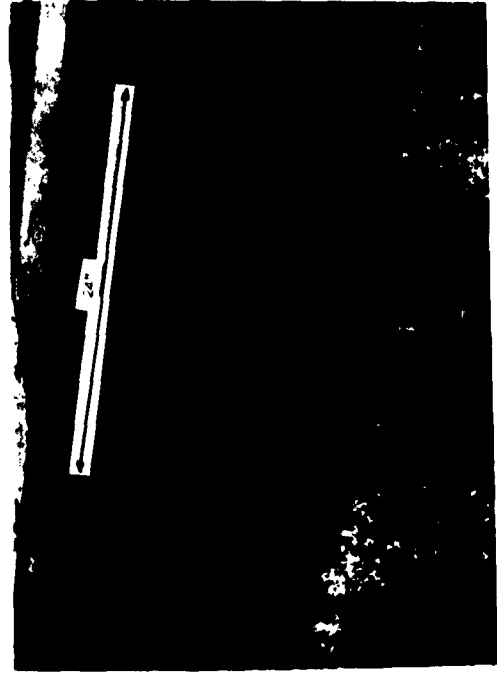
(a) Barnacles attached underneath the hydro-fender



(b) Barnacles attached to the Camel bulkhead

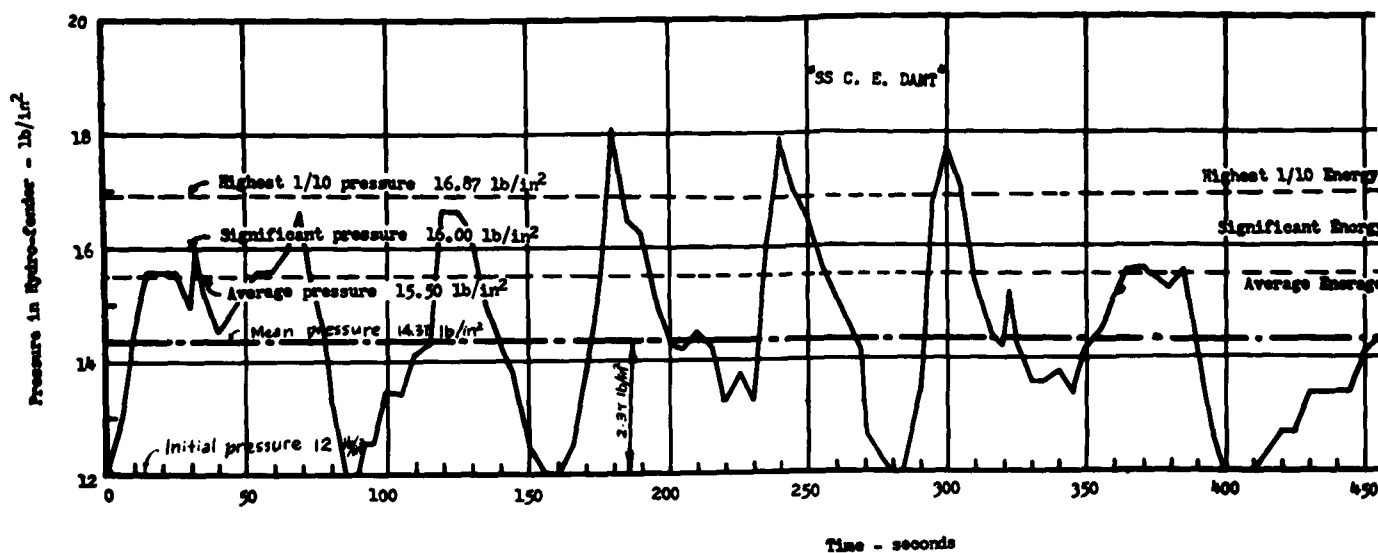


(c) Water screen of the hydro-fender not corroded

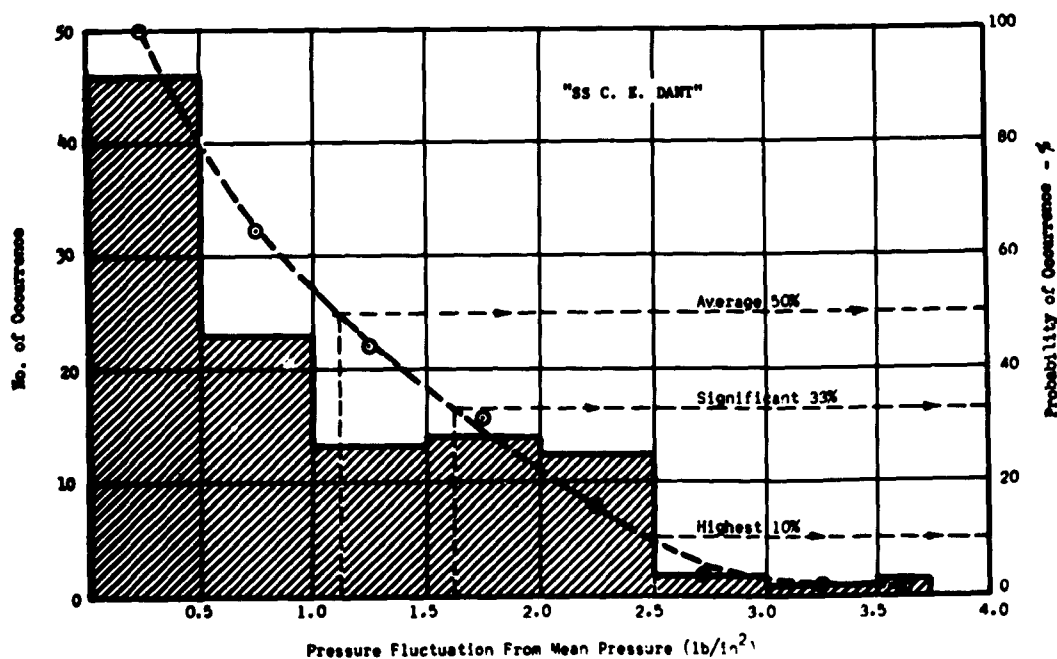


(d) Camel bulkhead wore in areas of contact with fender piles

Figure 13 Corrosion and Marine Growth Characteristics of Hydro-pneumatic Camel (three Months' immersion) (See also Fig. 12)



(a) Pressure Fluctuations Recorded



(b) Frequency Analysis

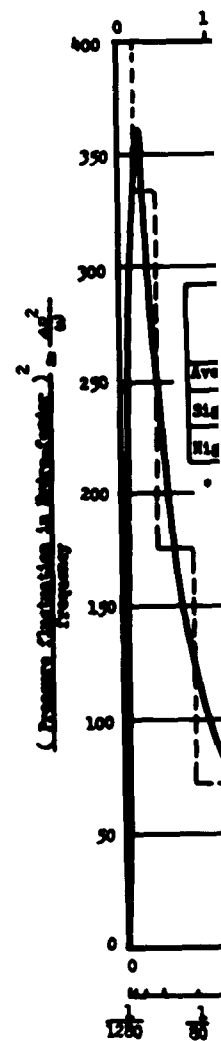
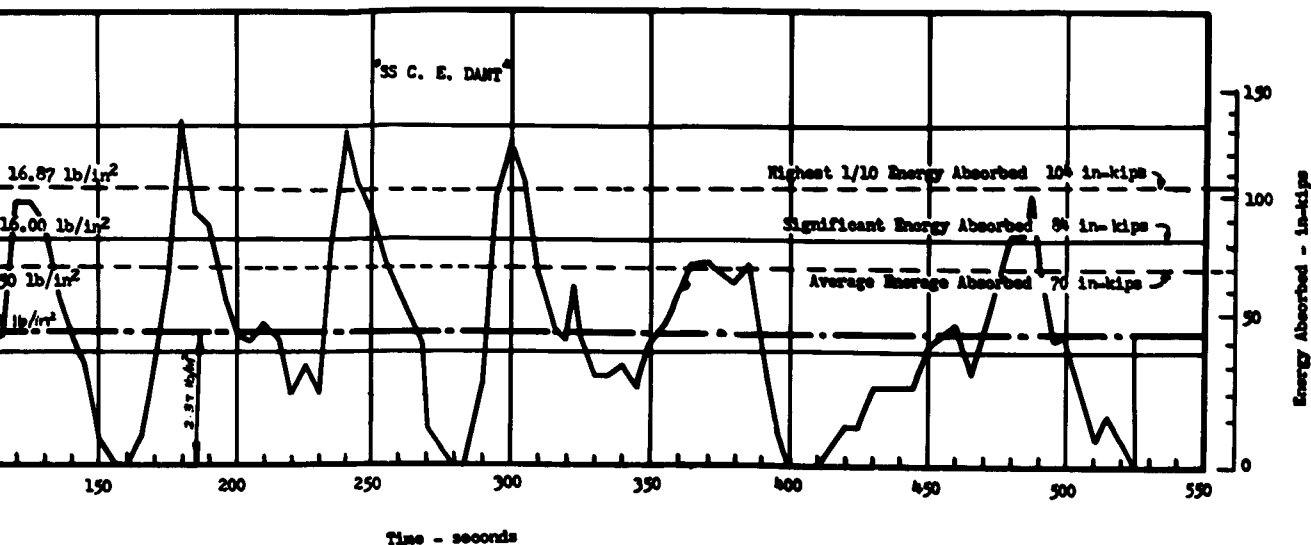
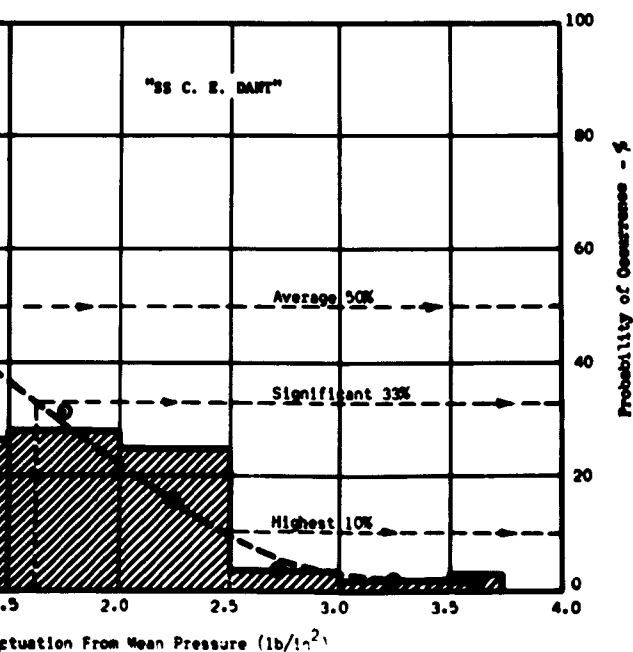


Figure 14 A Sample Spectral Analysis of Measured Pressures of a Pneumatic Fender.

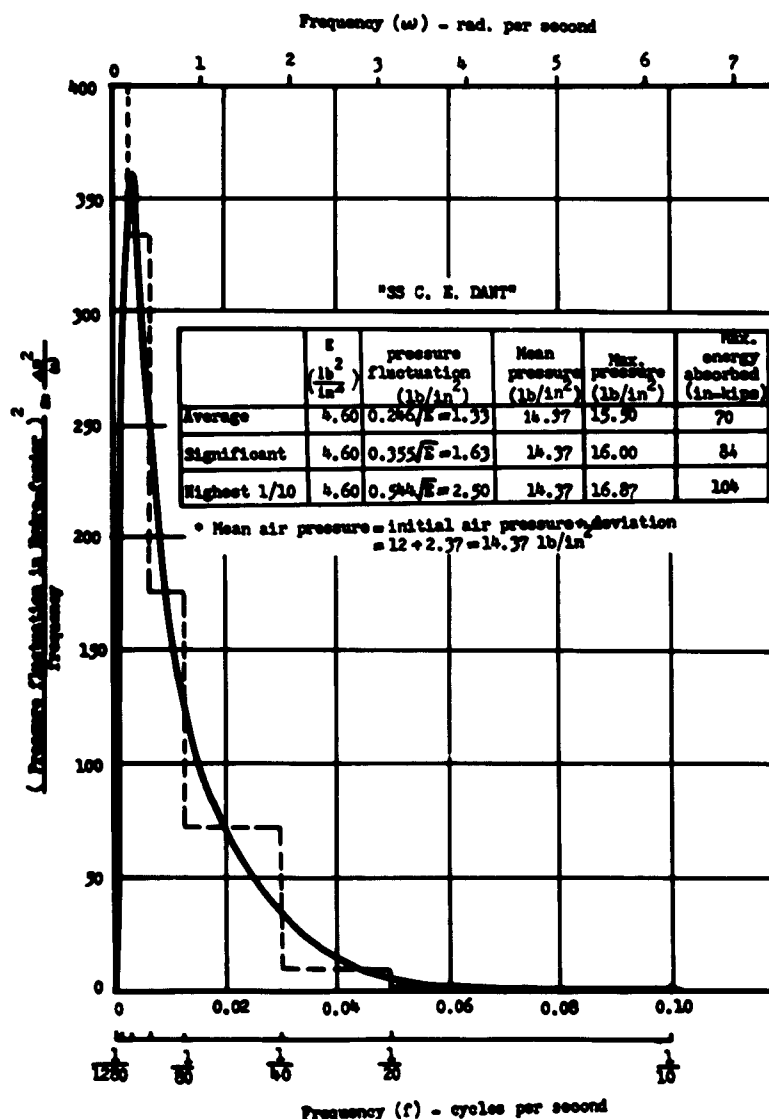


Pressure Fluctuations Recorded



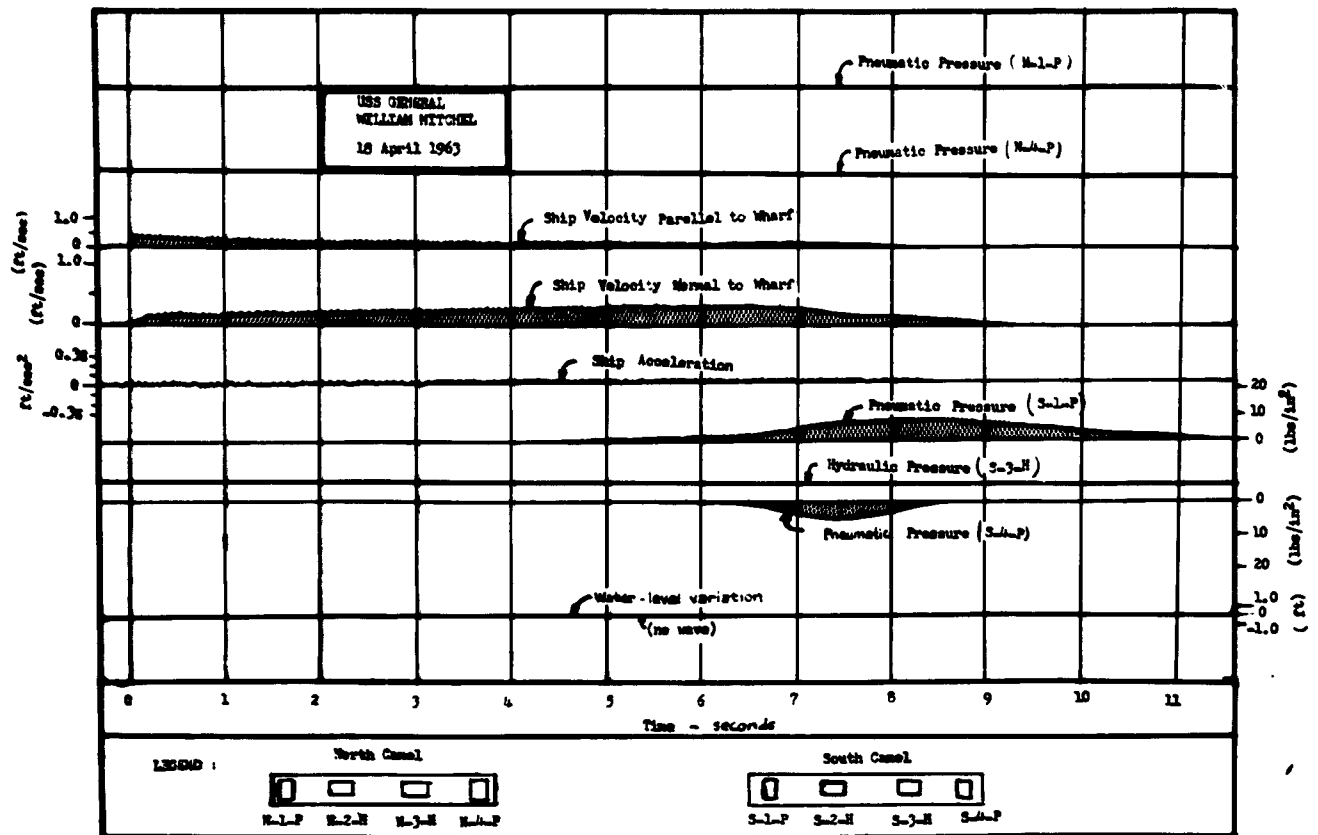
) Frequency Analysis

Statistical Analysis of Measured Pressures of a Pneumatic Fender.

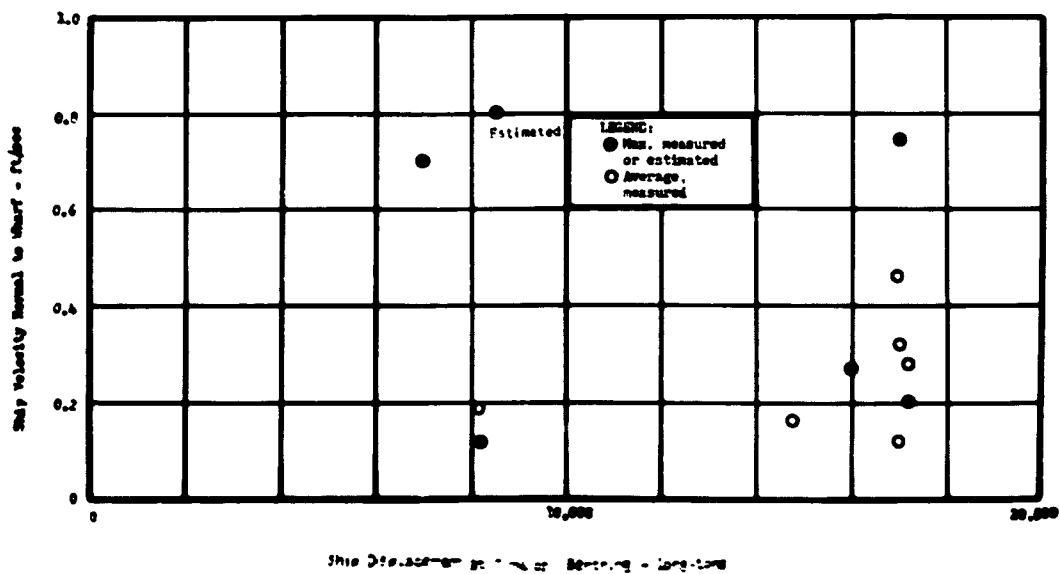


(c) Power Spectrum

2

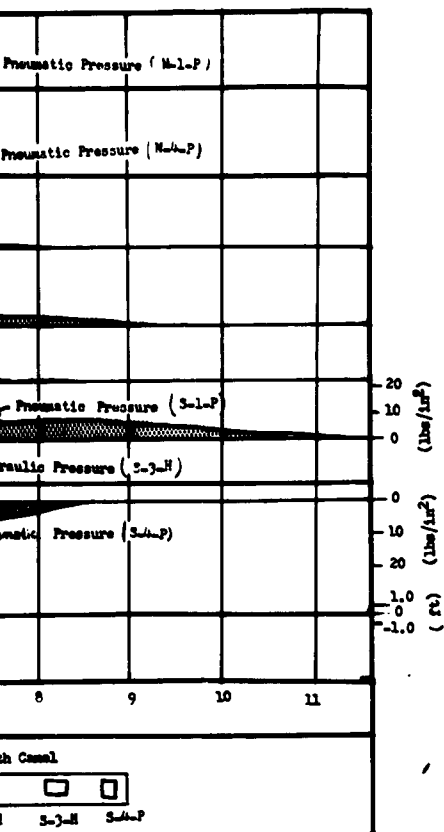


(a) Typical Recording of Field Measurements -
"USS General William Mitchell", 18 April 1963

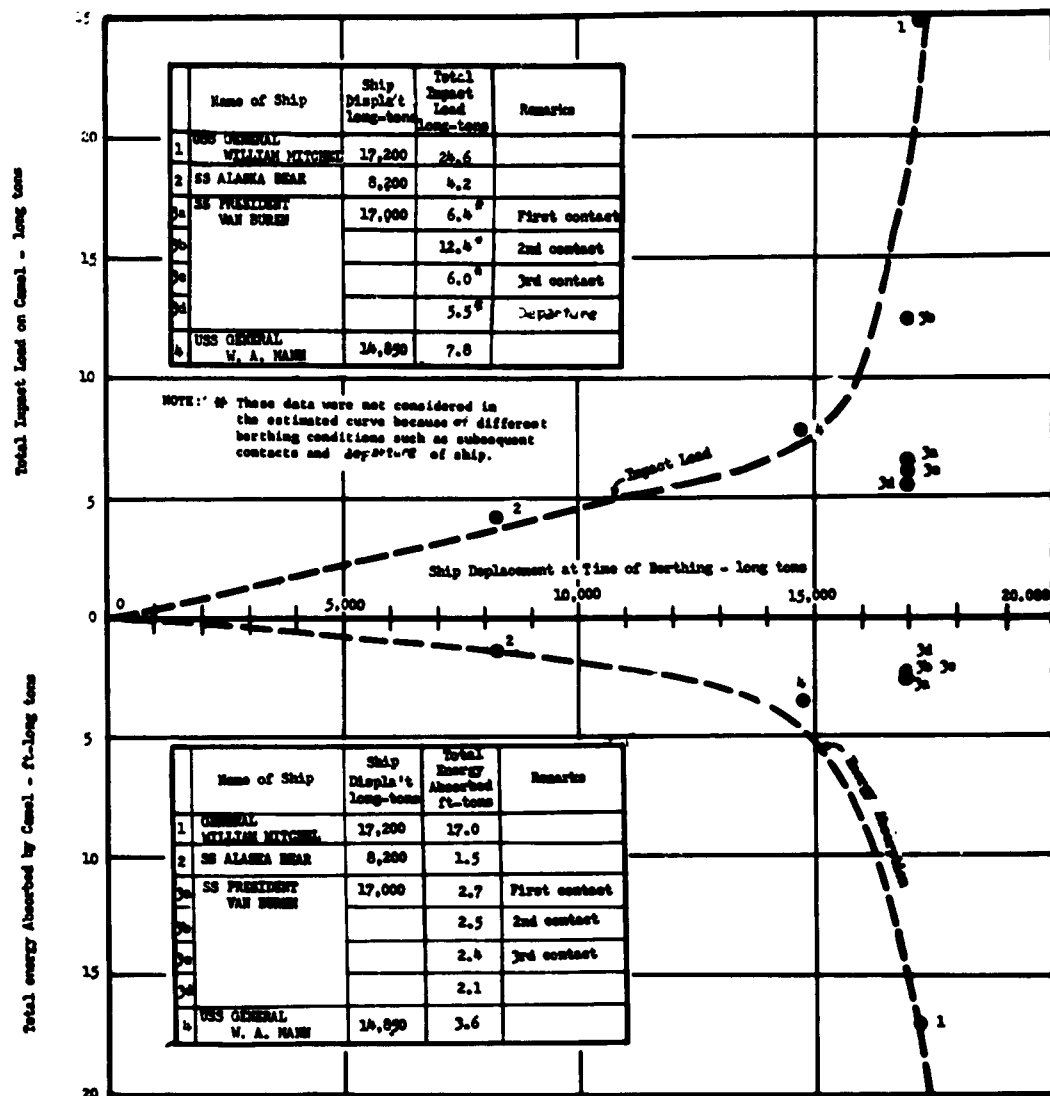
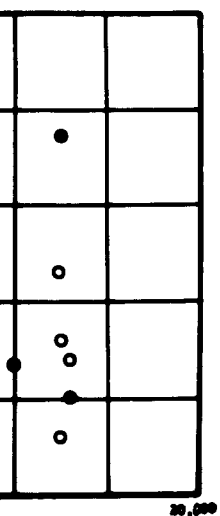


(b) Ship Velocity Component Normal to Wharf

Figure 15 Summary of Results and Inspection



CS -
1963



(c) Impact Load and Energy Absorption

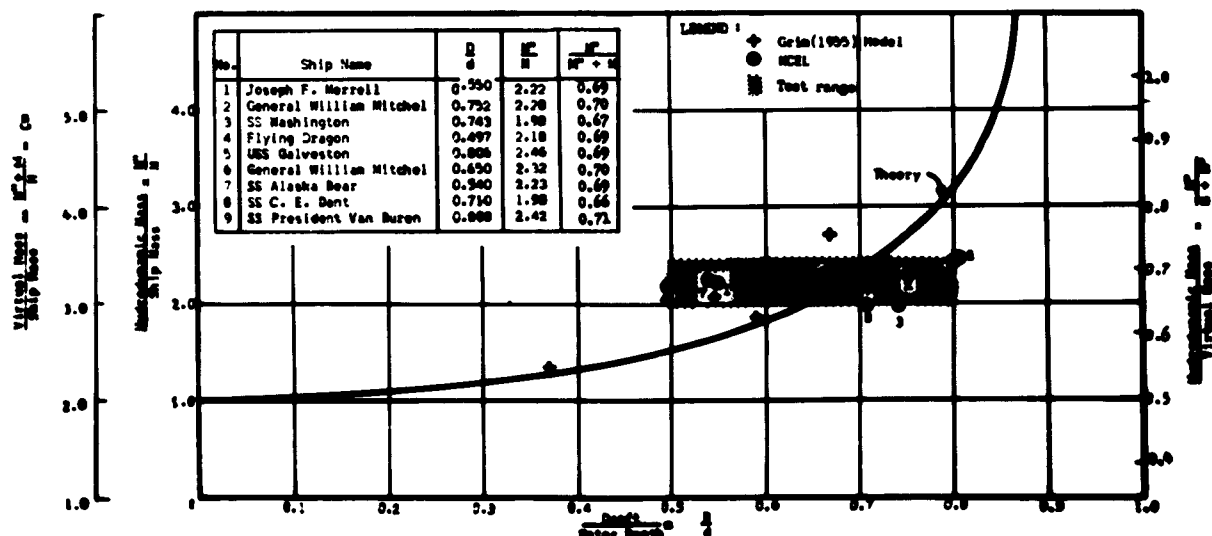


Figure 15 Summary of Results of Load Measurement and Inspection Program.

(d) Hydrodynamic Masses

2

TABLE I. Naval Architectural Characteristics of a
Hydro-Pneumatic Camel

Item	Unit	Quantity
Mass	slugs	1,105
Hydrodynamic mass in heave	slugs	450
Center of buoyancy above 18" pipe	ft	5.4
Center of gravity above 18" pipe	ft	3.6
Draft	ft	10.0
Beam	ft	1.7
Water depth, average	ft	32.0
Free period of oscillation in roll	sec	0.6
Free period of oscillation in pitch	sec	3.3
Free period of oscillation in heave	sec	4.7

Table II Summary of

Times of Berthing and Departure	Berthing Ship Characteristics										Wind		Env
	Name of Ship	Name of Captain	Type	Length (ft)	Beam (ft)	Draft (ft)			Displacement (long-tons)		Speed (knots)	Direction	
						Bow	Stem	Aft	Berthing	Full			
3/11/63 (0650) 3/14/63* (1317)	USNS PVT. JOSEPH F. MERRELL (T-AK-275) 												

Table II Summary of Results of Load Measurement and Inspection Program

Ship					Environment					Tugs		Berthing Procedure		Maximum Impact Load Measured (Long-tons)	Remarks
Draft (ft)		Displacement (long-tons)			Speed (knots)		Wave	Current	Water Depth	No. of Tugs	HP/Tug	Ship Approach Angle (Degrees)	Ship Approach Velocity (ft/sec)		
Bow	Starboard	Beam	Light	Full	Speed	Direction									
11.9	22.8	17.3	8,610	15,500	-	SE	Calm	-	31.5	2	1,030	20 then 0	0.8 (estimated)	Broadside (Stern half of ship contacted south camel first, and then moved forward approx. 60 feet longitudinally.)	Not measured
21.1	23.1	22.1 25.5 (full)	17,200	20,175	20 (gust up to 45 knots)	NW	Calm		29.4	2	1,030	0	0.2 (0.5 ft/sec estimated at the time of contact)	Broadside	Not measured
19	25.1	22 32 (full)	14,500	22,629	-	SE (120°)	Calm	no	29.6	2	1,030	25 then 0	(2 knots when approaching berth)	one fourth point, stern	Not measured
-	-	13.9	6,983	-	12	SW (250°)	-	no	28.0	2	1,030	15 then 0	0.70 (estimated)	one fourth point, stern	Not measured
24	25	24.5	15,000	15,000	8	S	no	no	31.0			45 then 180			Data not yet reduced (insignificant)
					high		rough								
18.0	23.0	20.5 25.3 (Full)	17,200	20,175	15	W	rough	no	31.5	2	1,030	0	0.27 (0.14 Aver.)	South camel only. No contact with north camel.	

Load Measurement and Inspection Program

Water Depth	Berthing Procedure			Maximum Impact Load Measured (Long-tons)	Maximum Energy Absorbed Measured (Ft-tons)	Comments			
	MS. of Tugs	MS. of Ship	Part of Ship Contacted Camel First			Ship Captain	Pilot and Others		
31.5	2	1,030	20 then 0	0.8 (estimated)	Broadside (Stem half of ship contacted south camel first, and then moved forward approx. 60 feet Longitudinally.)	Not measured	Not measured	(1) The idea of the test camels is excellent and should be performed (2) The camels would be undoubtedly helpful in reducing berthing damages, particularly to berths and ships subject to swell, surge action. (3) There was no possibility of damaging rubber fenders by ship bow impact in case of an angle approach. (4) It was a pleasant berthing because there was no jerk felt at the time of berthing. (5) The 5-foot distance between ship and dock face would present no serious cargo-handling problem. (6) The camels did function well during a great swell experienced. The bumping to the ship was avoided.	The port pilot, Captain Havemann, commented: (1) The test camels seemed workable under a skillful piloting condition. (2) The ship did not berth at the position as specified because an adequate space had to be reserved for another ship to be berthed at Wharf No. 5. The Marine Terminal Superintendent, of the Supply Department, CBC (Mr. C. A. Stine) commented: (1) The camels held the ship some five feet from the wharf face. This distance was considered too far for any cargo-handling operations. It would be no such problem if this distance could be reduced by 20 inches. Others: (1) The instruments of test camels have not yet been operated.
29.4	2	1,030	0	0.2 (0.5 ft/sec estimated at the time of contact)	Broadside	Not measured	Not measured	(1) The camels would be much more helpful to wharf than to berthing ship.	The port pilot, Captain Fosco, commented: (1) The berthing was smooth for safety reasons. (2) Would try higher berthing speed next time. The Tug Office, CBC, Chief Lepard, reported: (1) The maximum speed of gust observed was 40 knots. Others: (1) The instruments of test camels have not yet been operated.
29.6	2	1,030	20 then 0	(2 knots when approaching berth)	one fourth point, stern	Not measured	Not measured	(1) There was no difference felt with or without camels because weather and berthing conditions were so good. (2) The camels would be helpful under great swell conditions. (3) When the ship is berthing at a harbor exposed to swells, such as Natal, Brazil, use of ship anchors is needed for safety reasons. (4) The behavior of berthing depends on environmental conditions and captain's judgments.	(1) The "SS Washington" is a newly-built, cargo ship and no cargo-handling problem existed.
28.0	0	1,030	15 then 0	0.70 (estimated)	one fourth point, stern	Not measured	Not measured	(1) The idea of the test camel is good. (2) The water-filled rubber fenders seemed better than pneumatic ones.	
31.0			45 then 180			Data not yet reduced (insignificant)	Data not yet reduced (insignificant)	Inable to contact the ship captain because the officers were tied up for an open house to public.	(1) The berthing was extremely smooth. (2) The ship was approaching in an angle of 45°, then stopped and turned (with assistance of tugs) with bow toward the south in lieu of the north direction.
									(1) The mooring head of a pneumatic rubber fender was broken, presumably damaged by unknown barge. Repair cost was estimated at \$80, mainly for labor.
31.3	2	1,030	0	0.27 (0.14 Ave.)	South camel only. No contact with north camel.	24.6	17		A visit was made to the ship captain since he was visited previously. 3/14/63

Table II (Continued)

Time of Berthing and Departure	Berthing Ship Characteristics										Envl		
	Name of Ship	Name of Captain	Type	Length (ft)	Beam (ft)	Draft (ft)			Displacement (long tons)		Speed (knots)	Direction	We
4/22/63 (0400) 4/22/63 (1800)	SS ALASKA BEAR (Pacific Far East Line, Inc.)	David L. Parker	Victory Dry Cargo	455.2	62	10.5	28.5	16.8 28.5 (full)	8,200	15,300	5	NE (25°)	ca.
4/24/63 (0720) 4/24/63 (1735)	SS C. E. DART (Statens Line) Notes: 1948 newly-built ship	K. H. Jorgensen	Dry Cargo	345	76.1	13	26	19.5 32 (full)	12,900	22,620	27	W	ca.
4/30/63 (0750) 4/30/63 (1800)	SS PRESIDENT VAN BUREN (American President Lines)	Capt. Peterson	cargo	492	70	28	25	24 30 (full)	17,000	17,600	9	W	ca.
5/3/63 (0800) 5/7/63 (1915)	USS LT GEORGE W. G. ROYCE		Victory Dry Cargo	455	62	15	15	29 (full)	8,000*	15,500			
5/13/63 (0015) 5/16/63 (2225)	SS VOLUNTEER STATE (Statens Marine - Isthmian Agency)		Victory Dry Cargo	455	62	17	23	29 (full)	11,000*	15,500			
5/22/63 (0830) 5/22/63 (2045)	USS GENERAL HUGH J. GAFFEY (T-AP-121)		P-2 Trans- port	609	75	28	28	24.5	18,670	22,576		NW (130°)	
5/29/63 (0640) 5/29/63 (1800)	SS WASHINGTON (Statens Line)	John Steele	Dry Cargo	365	76.1	11	25	32 (full)	12,700*	22,620			
6/4/63 (0815) 6/5/63 (0900)	USS GENERAL W. A. MORGAN (T-AP-112)		P-2 Troop	622	78.5	19	21	25.5 (full)	14,850*	26,175			
6/9/63 (0715) 6/10/63 (0800)	SS OHIO (Statens Line)		C-3 Dry Cargo	492	70	15	22	18.5 (full)	11,000*	17,600			

* estimates

Table II (Continued) Summary of Results of Load Measurement and Inspection Program

Draft (ft)					Environment							Berthing Procedure			Maximum Impact Load Measured (Long-tons)	Maximum Kinetic Energy (ft-lb)
					Wind		Wave	Current	Water Depth	Tugs		Ship Approach Angle (Degrees)	Ship Approach Velocity (ft/sec)	Part of Ship Contacted Camel First		
Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
Direction						Speed (knots)	Direction	No. of Tugs	hp/tug							
Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
Direction						Speed (knots)	Direction	No. of Tugs	hp/tug							
Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
Direction						Speed (knots)	Direction	No. of Tugs	hp/tug							
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Direction						Speed (knots)	Direction	No. of Tugs	hp/tug							
Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
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Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
Direction						Speed (knots)	Direction	No. of Tugs	hp/tug							
Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
Direction						Speed (knots)	Direction	No. of Tugs	hp/tug							
Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
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Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
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Direction		Speed (knots)	Direction	No. of Tugs	hp/tug											
Direction						Speed (knots)	Direction	No. of Tugs	hp/tug							
Direction		Speed (knots)														

Results of Load Measurement and Inspection Program

			Berthing Procedure			Maximum Impact Load Measured (Long-tons)	Maximum Kinetic Energy Measured (Ft-tons)	Comments	
SHIP CHARACTERISTICS		Ship Approach Angle (Degrees)	Ship Approach Velocity (ft/sec)	Part of Ship Contacted Camel First	Ship Captain			Pilot and Others	
No. of Tugs	hp/tug								
2	1,030	0	0.12 (0.09 Aver.)	25 feet from c. g. of ship to stern	4.2	1.5	(1) The distance between the dock and ship berthed is con- sidered too far but this would not present any serious problem in cargo-handling. (2) The normal beam capacities ranged from 5 to 50 tons. (3) The simple-log camel is considered adequate for most merchant ships; there is no need for special-type camels such as the test camels. (4) The high-pressure inside the rubber fenders might dent the ship hulls. (5) The test camels have the advantage of distributing im- pact load to fender piles but are expensive, waste of money. No camels would stop accident- al ship-impact. (6) Consideration should be given to secure the rubber fenders directly to the fender piles.	The port pilot, (Captain R. E. Fosse) commented: (1) The cargo ship is too far away from dock for satisfactory self-loading and unloading operations. (2) The rubber fenders will be tearing loose by barges. (3) The half-pipes welded on ship-hull (from scupper to the water line) would tear the rubber fenders when ship surges. (4) The test camels would work well in large harbor basins. The port pilot (Captain Swanson) commented: (1) There is a law that the maximum dis- tance between dock and ship should not exceed 36". (2) Rubber tubes hanging on fender piles would be better than the test camels.	
2	1,030	—	—	—	Data not reduced	Data not reduced	(1) The idea of the test camel is very good; others said no good because they did not invent it. (2) It really helped the berthing without any feeling of jerks and bumps. (3) The camels would reduce unnecessary damages to both ships and docks. (4) There would be no danger to dent the ship hull due to high pressure. (5) There is no cargo-handling problem at all for ships of modern design. SS C. E. Dent can have five more feet away from the dock.	The port pilot (Captain R. E. Fosse) commented: (1) All rubber fenders of the southern camels were deflected more than 50% and were twisted due to excessive movements. (2) Two fender piles were broken because of high impact load at low tides. (3) The camels were tested and proved capable of withstanding high ship-impact.	
2	1,030		0.75 (0.50 Aver.) 0.06 (0.06 Aver.) 0.28 (0.28 Aver.) 0.16 (0.16 Aver.)		First hit 6.4 Second hit 12.4 Third hit 6.0 Leaving 5.5	2.7 2.5 2.4 2.1		(1) Ship captain was not visited. (2) The ship's anchor at bow was lowered for safety reasons because the winds were in the direction of berthing.	
								Load measurement and inspection program on this ship was not conducted.	
								Load measurement and inspection program on this ship was not conducted	
					Data not reduced	Data not reduced	Captain Anderson said, "First time I have seen anything in this form fenders, must say that in my opinion they are a big improvement toward pro- tection of ships hull and plating, and the docks."		
								Load measurement and inspection program on this ship was not conducted.	
					Data not reduced	Data not reduced			
								Load measurement and inspection program on this ship was not conducted	



APPENDIX A

WATER-ABSORPTION CHARACTERISTICS OF POLYURETHANE FOAM

The polyurethane foam (Lockfoam G-504) was tested in the Laboratory for water-absorption properties. The results showed that an average of 155% of water was absorbed after a four-week's immersion. Table III shows the water-absorption characteristics of Lockfoam G-504 samples tested.

Table III. Water-Absorption Characteristics of Polyurethane Foam (Lockfoam G-504)

Sample No.	Dry Weight Ounces	Wet Weight ^{1/} Ounces	Water Absorbed Ounces	Percent of Water ^{2/} Absorption
1	13.2	34.5	21.3	160
2	12.6	27.3	14.7	117
3	17.8	37.8	20.0	113
4	20.6	67.7	47.1	230
Average				155

Since the test camels were relatively water tight, the excessive absorption of water by the foam did not present a serious problem as far as buoyancy is concerned. The camels were floating with a draft of 10 feet (above the bottom of the ballast pipe) as compared with 10' - 9" as originally estimated.

- ^{1/} The wet weight of the foam sample was measured after a period of four weeks of submergence in fresh water. Water on the surface of the sample was cleaned with tissues before weighing.
- ^{2/} The variance of water-absorption characteristics is probably due to different exposed areas and different quality of foaming.

APPENDIX B

CREOSOTING TREATMENT OF CAMEL

All timber members were treated with coal-tar creosote oil at the NCEL's creosoting plant (Chapin, 1963)⁷. The retentions of preservative vary from 18 to 26 pounds per cubic foot of Douglas Fir treated.

A comparison of the degree of penetration with standard requirements is shown in Table IV.

Table IV. Full-Cell Pressure Treatment to Refusal of Pacific Coast Douglas Fir for Use in Coastal Waters

Source of Information	Retention of Preservative (lb/ft ³)	Remarks
NCEL Camel	18 - 26	20 lb/ft ³ in average
West Coast Lumbermen's Association (1958) ⁸	12	
Merritt (1958) ⁹	16 - 20	For teredo-infested harbors
American Wood-Preservers Association, (1962) ¹⁰	12 - 16	The higher retentions and corresponding penetrations are recommended for severe service conditions.

APPENDIX C

COST ESTIMATES OF CAMELS

The Hydro-pneumatic Camel is considered expensive as compared with a single-log camel but less expensive than those suggested by NCEL (Leendertse, 1962). For normal operations, a pair of camels is required. In addition, simple-log camels should be provided to protect the fender piles which are not covered by the camels. A cost comparison is shown in Table V.

Table V. Estimated Costs of Camels of Different Types for Berthing Ships of 20,000 Tons Displacement

Type	No. of Camel Units Required		Total Cost ^{4/}	Unit Cost Dollars per Ft.		Unit Cost Dollars Per Ft. of Berth
	Camel	Log		Camel	Log	
Hydro-Pneumatic Camel ^{1/}	2	17	\$42,160	\$360 ^{5/}	\$12	\$68
Hydraulic or Torsional ^{2/} Camel (Leendertse, 1962)	6	17	\$66,340	\$600	\$12	\$107
Simple Log ^{3/}		21	\$13,440		\$12	\$12

NOTES:

^{1/} Designed by Engineering Division, Office of Engineering and Construction, Bureau of Yards and Docks, Washington, D. C. Each camel is 50 feet long.

^{2/} Designed by Harbor Division and Design Division, U. S. Naval Civil Engineering Laboratory, Port Hueneme, California. Each camel is 17 feet long.

^{3/} Existing log-camel being used without energy absorption except for load distribution characteristics.

^{4/} Total cost is estimated for a total berth of 620 feet, designed for ships of 20,000 tons displacement.

^{5/} Includes \$20.0/ft for creosoting cost (unit cost: \$4.0/ft³ of timber treated).

APPENDIX D

INSPECTION OF ENVIRONMENTAL DAMAGE TO RUBBER FENDERS AND FLOATING WOODEN BULKHEAD

by

C. V. Brouillette

1. On 28 May 1963 subject inspection was made by Mr. T. Lee and Mr. C. V. Brouillette. The items of particular interest were (a) the rubber fenders, (b) the floating wooden bulkhead, (c) the water screen filter, (d) the mooring chain, and (e) the ballast pipe.
2. The rubber fenders showed no evidence of deterioration. The sides of rubber fenders near the top surface were covered with a heavy growth of algae, Figure 12c. Only a small amount of fouling and slime remained on the sides of the fenders because of the rubbing action from ships and the floating bulkhead. No mechanical damage from this rubbing action was observed. The lower area and the bottom of the fenders were covered with small barnacles and brown algae, Figure 13a. The adhesion of attachments of fouling on the rubber fenders was light and the fouling was easily scraped off.
3. The vertical rubber fenders were filled with pressurized air and maintained a full symmetric shape. The horizontal fenders were filled with water and presented a slightly collapsed shape after being lifted from the water for inspection, Figure 12a.
4. The floating wooden bulkhead had light algae growth over small scattered areas near the water line, Figure 12c. Where the rubber fenders rubbed, the wooden surfaces were slightly abraded and the wood was lighter in color here when compared to the black creosote on the adjacent surfaces, Figure 13d. Light coverage of small barnacles appeared over the wooden surface of the floating bulkhead, Figure 13b. Bryozoa and hydroids were also present to a considerable extent. No evidence of Limnoria or boring animals were evident.
5. The chain attached to the ballast pipe was rusting between the links. The bolts and nuts which held the caps onto the

ballast pipe were severely rusted. The coating on the sea water screen filter had failed and the water screen filter was severely rusted, Figure 13c. The coating on the ballast pipe was abraded in several areas and light rusting was occurring here, Figure 12d. Also rusting was occurring along many of the welds.